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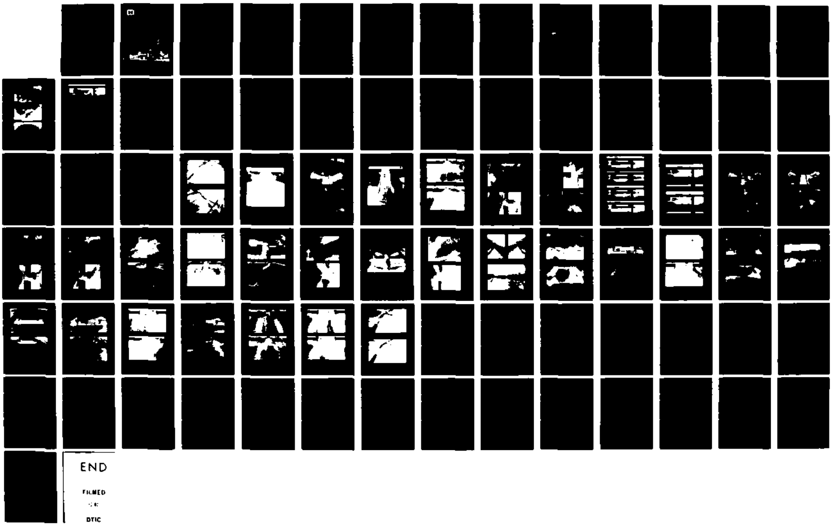

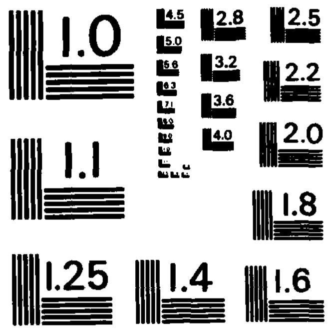
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TECHNICAL REPORT HL-82-22

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SOUTH FORK TILLATOBA CREEK DROP STRUCTURES, MISSISSIPPI

Hydraulic Model Investigation

by

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Final Report

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The South Fork of Tillatoba Creek, Mississippi, has experienced a relatively rapid stage of channel degradation accompanied by severe streambank erosion. A two-stage, reinforced-concrete grade-control structure is proposed for construction by the U. S. Department of Agriculture, Soil Conservation Service, on the South Fork of Tillatoba Creek. Tests were conducted on a 1:29-scale section model of the low-stage structure

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20. ABSTRACT (Continued)

and a 1:25-scale model of the grade-control structures to verify design criteria, evaluate the hydraulic performance of the structures, and make modifications to the design, where needed, to improve performance. The 1:25-scale model reproduced both the high- and low-stage control structures, approximately a 500-ft length of the upstream approach, and an 1,100-ft length of the topography downstream from the structures. Flow conditions in the approach to the low-stage structure were improved with design modifications. Energy dissipation in the low-stage structure stilling basin was improved by the addition of a trajectory curve type of drop. Approach wing walls improved flow conditions in the high- and low-stage structure stilling basins. The widths of the exit channels for both the high- and low-stage structures were reduced from their original design. Improvements were made to flow conditions in the high-stage structure exit channel by eliminating the preformed scour hole, and stable riprap designs were determined.

PREFACE

The model investigation reported herein was authorized by the Office, Chief of Engineers, U. S. Army, on 27 May 1980 at the request of the U. S. Army Engineer District, Vicksburg (LMKED). The studies were conducted by personnel of the Hydraulics Laboratory, U. S. Army Engineer Waterways Experiment Station (WES), during the period November 1980 to December 1981. All studies were conducted under the direction of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, and J. L. Grace, Jr., Chief of the Hydraulic Structures Division. Tests were conducted by Messrs. J. E. Hite, Jr., T. E. Murphy, Jr., and J. F. George under the supervision of Mr. G. A. Pickering, Chief of the Locks and Conduits Branch. This report was prepared by Messrs. Hite and Pickering.

During the course of the investigation, Messrs. D. Ralston, E. Alling, P. Forsythe, K. M. Hayward, W. L. Leeming, R. C. Daniel, and C. Myers of the Soil Conservation Service visited WES to discuss model results and correlate these results with concurrent design work.

Commanders and Directors of WES during the testing program and the preparation and publication of this report were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic metres per second
feet	0.3048	metres
feet per second	0.3048	metres per second
inches	25.4	millimetres
miles (U. S. statute)	1.609344	kilometres
pounds (mass)	0.4535924	kilograms
square miles	2.589988	square kilometres

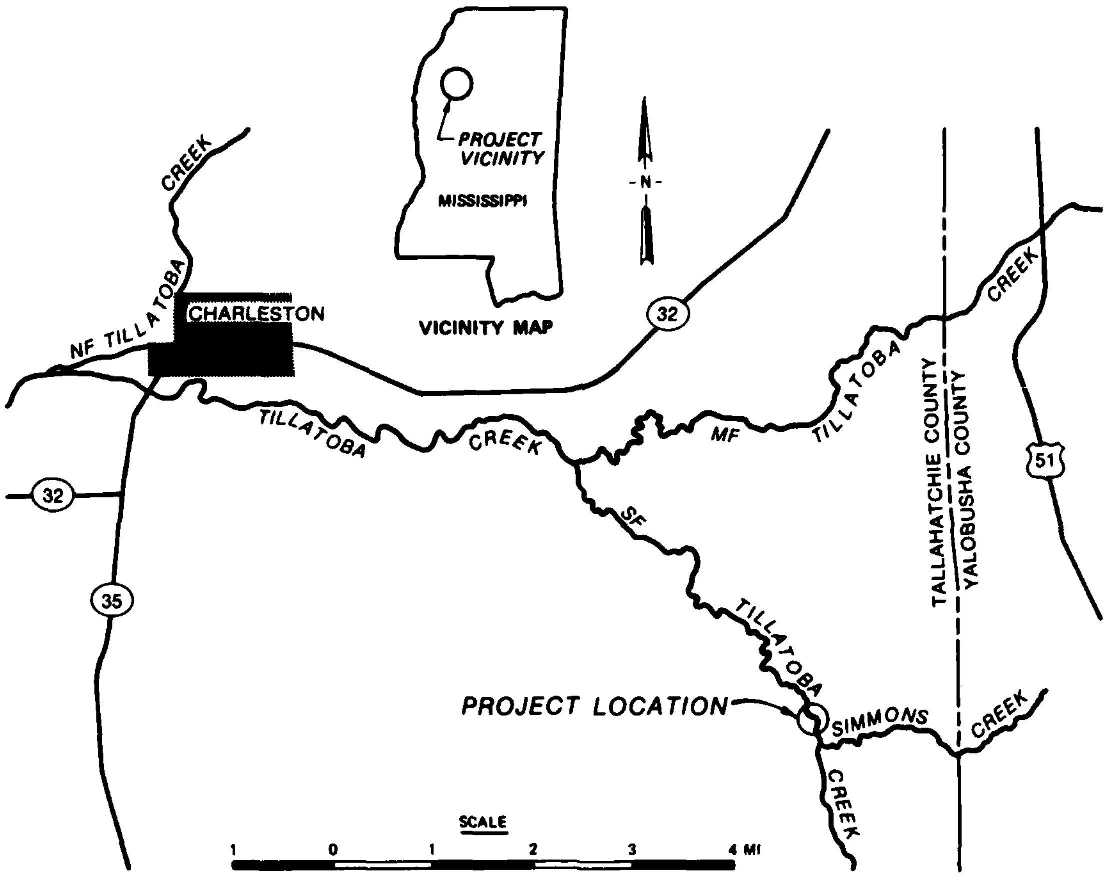

Figure 1. Project location

SOUTH FORK TILLATOBA CREEK DROP STRUCTURES, MISSISSIPPI

Hydraulic Model Investigation

PART I: INTRODUCTION

Background

1. The South Fork of Tillatoba Creek, located in the northcentral part of the State of Mississippi (Figure 1), enters Tillatoba Creek about 4 miles* east of Charleston, Mississippi. Tillatoba Creek is located in the Yazoo River Basin.

2. The drainage basin of South Fork Tillatoba Creek comprises an area of about 60 square miles, primarily forest lands but also containing pasture and croplands. Topography of the basin varies from steep hills in the headwaters to nearly level to gently rolling lands along the stream. Elevations range from about 200 to 500 ft NGVD.** The bed material of this stream consists of sand and some gravel, and the banks are predominantly silt. South Fork Tillatoba Creek is undergoing a relatively rapid stage of channel degradation accompanied by severe streambank erosion resulting in the loss of valuable agricultural lands. In the degraded state, the stream is 200 to 400 ft wide and 20 to 25 ft deep. Upstream of the present terminus of degradation, South Fork Tillatoba Creek and Simmons Creek exist in a more natural condition with banks 20 to 50 ft wide and shallower depths. General flooding in the drainage basin upstream of the confluence of South Fork Tillatoba Creek and Simmons Creek occurs an average of four times per year and is of sufficient depth and duration to cause damage to crops, pasture, roads, and bridges. Due to the severe degradation, the channel of South Fork

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

** All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

Tillatoba Creek downstream of the confluence with Simmons Creek has developed a capacity such that overbank flooding will be an extremely rare event.

3. Streambank stabilization measures have been performed by both the Soil Conservation Service (SCS) and U. S. Army Engineer District, Vicksburg, on the lower reaches of South Fork Tillatoba Creek. Two grade-control structures are to be installed to significantly reduce channel degradation and accompanying erosion.

Purpose of Model Investigation

4. The South Fork structures are larger than those previously modeled and used as a basis for the hydraulic design criteria presently used by SCS. Therefore, a model study of the South Fork structures was conducted to verify the design criteria, evaluate the hydraulic performance of the structures, and make modifications to the design, if needed, to improve performance. Specifically, the model study was to determine:

- a. Geometric changes to the structures to improve hydraulic performance.
- b. Discharge capacity.
- c. Stilling basin performance.
- d. Riprap requirements.
- e. Approach and exit channel configurations.

Project Design

5. The project is designed as separated high- and low-stage structures with an emergency spillway. Details of the project are shown in Plate 1. The low-stage weir crest elevation of 222.0 was set to obtain an assumed stable grade of 0.0007 ft/ft. The end sill elevation of 212.0 was set at the anticipated degraded elevation in the downstream channel. The weir length of 29 ft was sized to carry the bank-full inlet channel capacity for an aged condition. The high-stage weir crest

elevation of 232.0 was set at the floodplain elevation. The high-stage end sill elevation (221.0) was set at the tailwater elevation created by the discharge through the low-stage structure when the headwater is at the floodplain elevation of 232.0 using assumed ultimate degraded conditions in the outlet channel. The weir length was selected so that the downstream channel would be filled when the water surface upstream from the structures would be at the emergency spillway crest elevation of 240.0. Details of the low-stage structure are shown in Plate 2, and details of the high-stage structure are shown in Plate 3.

PART II: THE MODEL

Description

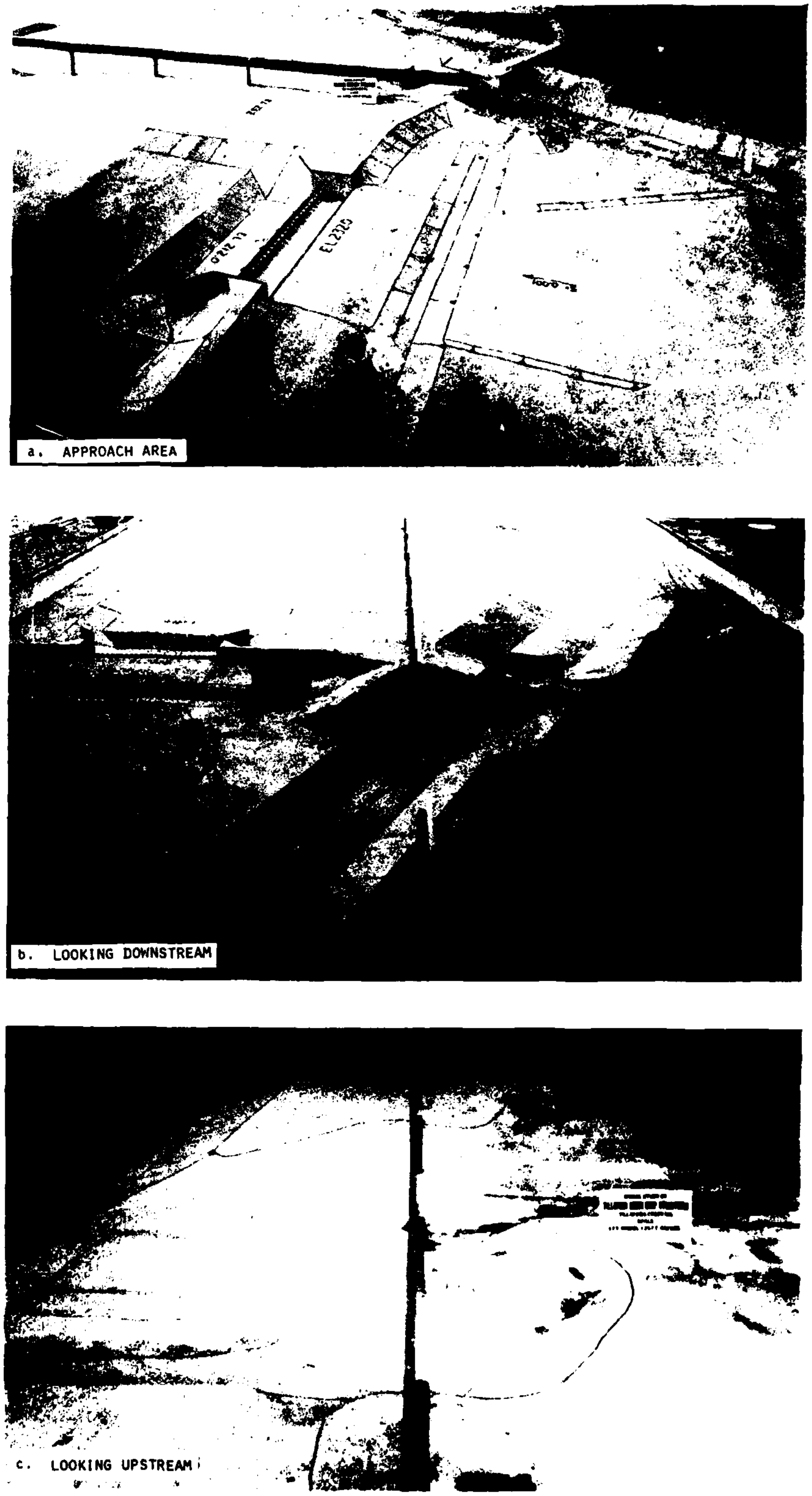
6. The 1:25-scale model reproduced both the high- and low-stage control structures, approximately a 500-ft length of the upstream approach and an 1,100-ft length of the topography downstream from the structures (Figure 2). The high- and low-stage structures were constructed of plastic-coated plywood. Initially, the approach channel, nonoverflow sections, and exit channel were molded in sand and cement mortar to sheet-metal templates to observe the hydraulic performance and discharge characteristics. In later tests, the cement mortar was replaced with sand and riprap to check the adequacy of the riprap protection upstream and downstream from the structures. Cloth was placed between the sand and graded riprap to provide separation of materials during all riprap tests. Also, to study the effect of a curved trajectory type of drop on the flow conditions in the stilling basin, a 1:29-scale section model was constructed in a glass-sided flume (Figure 3).

Model Appurtenances

7. Water used in operation of the models was supplied by a circulating system. Discharges in the models were measured with venturi meters installed in the inflow lines and were baffled when entering the model. Water-surface elevations and soundings over the sand and riprap beds downstream from the structure were measured with point gages. Velocities were measured with pitot tubes mounted to permit measurement of flow from any direction and at any depth. The tailwater in the lower end of the model was maintained at the desired depth by means of an adjustable tailgate. Different designs, along with various flow conditions, were recorded photographically.

Scale Relations

8. The accepted equations of hydraulic similitude, based on the



a. APPROACH AREA

b. LOOKING DOWNSTREAM

c. LOOKING UPSTREAM

Figure 2. General view of model

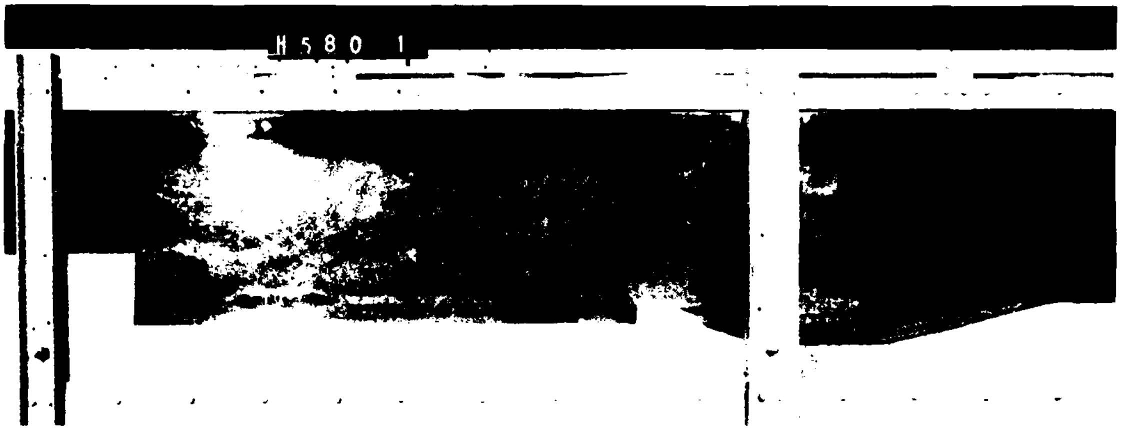


Figure 3. The 1:29-scale section model

Froudian criteria, were used to express mathematical relations between the dimensions and hydraulic quantities of the model and prototype. General relations for the transference of model data to prototype equivalents are presented below:

Characteristic	Dimension*	Model:Prototype	Model:Prototype
Length	L_r	1:25	1:29
Area	$A_r = L_r^2$	1:625	1:841
Velocity	$V_r = L_r^{1/2}$	1:5	1:5.39
Discharge	$Q_r = L_r^{5/2}$	1:3,125	1:4,529
Volume	$V_r = L_r^3$	1:15,625	1:24,389
Weight	$W_r = L_r^3$	1:15,625	1:24,389
Time	$T_r = L_r^{1/2}$	1:5	1:5.39

* Dimensions are in terms of length.

Because of the nature of the phenomena involved, certain of the model data can be accepted quantitatively, while other data are reliable only in a qualitative sense. Measurements in the model of discharges, water-surface elevations, velocities, and resistance to displacement of riprap material can be transferred quantitatively from model to prototype

by means of the above scale relations. Evidence of scour of the model sand bed, however, is to be considered only as qualitatively reliable since it has not yet been found possible to reproduce quantitatively in a model the resistance to erosion of fine-grained prototype bed material. Data on scour tendencies provided a basis for determination of the relative effectiveness of the different designs and indicated the areas most subject to attack.

PART III: TESTS AND RESULTS

9. Several tests were conducted to observe and measure the hydraulic performance of the control structures with the original design and with various modifications to the structures (Table 1). With most of the design modifications tested, current velocities and patterns, water-surface elevations, and sand scour cross sections downstream from the structures were measured. Although the sand scour depths measured in the model are not necessarily representative of the exact depths in the prototype, they provide a good means for comparing the relative merits of various design modifications. Each scour test consisted of simulating a flood hydrograph of 17.5-hr (prototype) duration with a peak discharge of 14,800 cfs.

Initial Tests

10. Initial tests were conducted to observe and document flow conditions in the approach area and exit channels of the low- and high-stage structures for a headwater elevation of 240.0. El 240.0 is the crest elevation of the emergency spillway (which was not reproduced in the model). The discharge determined from a calibration curve (Plate 4) obtained with the original design for a headwater elevation of 240.0 was 14,800 cfs, the design discharge used for the model study. Flow conditions with the 14,800-cfs discharge and the original design structures are shown in Photo 1. Velocities measured in the approach and exit channel of the low-stage structure are shown in Plate 5 and the velocities measured in the approach and exit channel of the high-stage structure are shown in Plate 6.

Low-Stage Structure

Approach area

11. In the approach area to the low-stage structure, flow around the right (looking downstream) approach dike formed eddies that moved

into the entrance channel (Photo 1). Flow into the structure was not uniformly distributed and entered in a left-to-right fashion, striking the right inside stilling basin wall. Approach velocities entering the structure were higher on the left side as shown in Plate 5.

12. Approach conditions were improved by modifying the right approach dike. Flow conditions were observed as the dike was shortened in 25-ft increments from the original length of 125 ft. A 25-ft-long dike was determined to be the appropriate length that provided a uniform distribution of flow entering the structure. Approach flow conditions with the shortened dike are shown in Photo 2. Eddies present in the entrance channel with the original design approach were eliminated by this modification.

Abutments

13. The square abutments of the entrance to the low-stage drop structure as originally designed (Plate 2) caused separation of flow from the walls at the weir and resulted in concentration of flow in the center of the stilling basin as shown in Photo 3. Energy dissipation in the stilling basin was adversely affected by this contraction of flow at the abutments. Scour downstream from the structure resulting from the flow hydrograph discussed in paragraph 9 is shown in Photo 4. Cross sections of the scour hole are shown in Plate 7; the maximum depth of scour was 11 ft.

14. Although the model abutments could be rounded to study the proposed structure, the sponsor requested that tests be conducted with modifications that could easily be applied to existing structures with similar designs. A 2-ft-radius semicircle that could be constructed from a 4-ft-diam pipe was attached to the abutment immediately upstream from the weir. This curve extended the full depth of the abutment. This modification improved flow conditions slightly, but the radius appeared too small. The 2-ft-radius curve was replaced with a 3-ft-radius curve as shown in Plate 8, which was more effective in improving flow conditions and could be constructed from a 6-ft-diam pipe.

15. As a result of the tests conducted with the semicircles, a 3-ft-radius curve was formed on the abutments of the weir (type 2

abutments, Plate 8). This modification distributed flow across the weir better than the original abutment, as shown in Photo 5. However, there was still some flow concentration in the stilling basin.

16. Tests were conducted with abutments and approach wing walls of several sizes and configurations as shown in Plate 8. Approach wing walls consisting of four 8-ft-chord sections (type 7 design) as shown in Plate 8 were found to uniformly distribute flow and improve energy dissipation in the stilling basin. The chord sections were used rather than a curve because of ease of construction in the prototype structure. Flow conditions in the basin are shown in Photo 6. Scour tests were conducted with the type 2 design abutments and the type 7 design approach wing walls to determine the relative effectiveness of energy dissipation with the two designs. These tests were conducted after the exit channel width had been reduced (Plate 9), which will be discussed later in this report. Scour downstream from the stilling basin after tests with the type 2 design abutments and the type 7 design approach wing walls is shown in Photos 7 and 8. Scour cross sections are shown in Plates 10 and 11. The maximum depth of scour was approximately 2 ft less with the type 7 design approach wing walls.

Stilling basin

17. The low-stage structure stilling basin, Plate 2, was designed for flow conditions that submerge the weir. When the tailwater increases, creating a greater submergence of the weir, flow over the vertical drop plunges at a greater distance downstream in the basin until it eventually rides the surface of the tailwater. Thus, the length of the stilling basin, 100 ft, was longer than a conventional hydraulic-jump type stilling basin. The tailwater depth above the crest with the design flow is 12.3 ft. Thus, the submergence at the structure (the ratio of tailwater depth above the crest to critical depth of flow) is greater than the available criteria needed for design of the stilling basin length for this type of drop structure. Additional basic research is needed for drop structures with high submergence.

18. A 1:29-scale section model, constructed in a glass-sided

flume, was used to determine the tailwater elevation where flow plunged into the stilling basin (Photos 9a and 9b), and where flow rode the surface of the tailwater (Photos 9c and 9d). Results of tests conducted to determine the tailwater elevation where flow began to ride the surface with various discharges are shown in Plate 12.

19. A curved trajectory was placed downstream from the weir to cause flow to plunge into the stilling basin with higher tailwater elevations to obtain better energy dissipation. The shape of this parabolic trajectory ($X^2 = 40Y$) was based on previous studies conducted with low-head navigation spillways. This was designated the type 3 design crest (Plate 13). Flow followed the curve into the basin at tailwater elevations higher than those with the straight drop as snown in Photo 10 and Plate 12.

20. Although the type 3 design crest improved flow conditions over the original design, tests were conducted with a longer parabolic curve of the crest in an effort to further improve energy dissipation. The shape of this curve ($X^2 = 72Y$) was based on the theoretical trajectory of a free jet with a design head of 18 ft. The design head of 18 ft was based on the pool elevation of 240.0 with the design discharge and the weir crest elevation of 222.0. Details of this curve (type 4 design crest) are shown in Plate 13. Tailwater elevations at which flow began to ride the water surface with various discharges are shown in Plate 12. There was a slight improvement of the conditions with this design when compared with the type 3 design crest, and considerable improvement when compared with the original design (compare Photos 9c, 10, and 11 and data in Plate 12).

21. After the crest shape tests were conducted in the section model, each design was installed in the 1:25-scale model with the type 2 design abutments. Flow conditions were observed and sand scour tests, as discussed in paragraph 9, were conducted. The sand scour cross sections were compared to determine the relative amount of energy dissipation achieved with the various designs. Scour resulting from a test with the type 3 design crest is shown in Photo 12. Scour cross sections are shown in Plate 7. Scour generally was slightly less than

with the original design. The maximum scour depth was 10 ft compared with 11 ft with the original design. Scour resulting from a test with the type 4 design crest is shown in Photo 13, and cross sections are shown in Plate 7. The maximum depth of scour was 6 ft. Comparison of all of the scour cross sections shows that a greater amount of energy dissipation occurred with the type 4 design crest.

22. As previously stated, the stilling basin as originally designed was longer than a conventional hydraulic-jump type stilling basin, and the baffle blocks were larger and farther downstream. After the type 4 design crest was developed to direct more flow into the stilling basin, tests were conducted to determine if the baffle blocks could be moved upstream and reduced in size. Also, a second row of baffle blocks was added. This resulted in a hydraulic-jump type stilling basin that had produced good energy dissipation in previous model studies with tailwater elevations near those required for a hydraulic jump free of submergence effects. The size and configuration of the blocks are shown in Plate 13 as the type 2 design baffle blocks. Scour tests were conducted with both the original baffle blocks and the type 2 design baffle blocks in combination with the type 4 design crest and the type 7 design approach wing walls to determine the relative amount of energy being dissipated with each design. Scour resulting with the original design baffle blocks is shown in Photo 14 and Plate 11; scour resulting with the type 2 design baffle blocks is shown in Photo 15 and Plate 11. Comparison of these data indicates that the type 2 design baffle blocks were much less effective in dissipating energy. The depth of scour (12 ft) with the type 2 design baffle blocks was almost two times as much as that with the original design baffle blocks (6 ft). This was attributed to the excessive depth of tailwater available with the design discharge. Since these tests indicated that a conventional hydraulic-jump type stilling basin would not be effective for this structure, no other baffle arrangements were tested.

Riprap protection plan

23. The riprap plan (Plate 1) as originally designed for the low-stage structure consisted of riprap with an average diameter (D_{50}) of

12 in. and a blanket thickness of 18 in.; riprap gradation is shown in Plate 14. The original configuration of the riprap plan in the approach area was modified due to the reduced length of the right approach dike as discussed in paragraph 12. The model with the riprap in place is shown in Photo 16.

24. Tests were conducted to determine if the protection provided by the plan was adequate. Riprap remained stable throughout a series of tests consisting of a 5-hr duration with a total discharge of 3,100 cfs through the low-stage structure and a 5-hr duration with a total discharge through both structures of 14,800 cfs. Riprap remained stable throughout several of the scour tests previously discussed. Based on these tests, it was concluded that the original plan would provide adequate protection upstream and downstream from the structure.

Exit area

25. Flow conditions in the exit channel with normal tailwater, el 234.3, and with the tailwater expected with the ultimately degraded channel, el 233.0, and the design discharge are shown in Photo 17. Eddies formed in the exit channel in the vicinity of the wing walls. Sandbars developed on each side of the channel as shown in the scour cross sections in Plate 7. It appeared that the strength of the eddies was increased by the wing walls at the downstream end of the structure, and the wide exit channel (80 ft) relative to the width of the stilling basin (29 ft).

26. The bottom width of the exit channel was reduced to 39 ft, 5 ft wider than the stilling basin on either side, and the exit wing walls were removed. Details of these modifications are shown in Plate 9 and Photo 18. The intensity of the eddies was reduced as shown in Photo 6. Scour tests were conducted with the original exit channel and with the modified exit channel (39-ft base width). The type 4 design crest was in place for these tests. Scour with the original exit channel is shown in Plate 7 and Photo 13; scour with the modified exit channel is shown in Plate 10 and Photo 19. As shown in these data, an improvement was realized with the modified exit channel. Since much less excavation would be needed for the narrower channel, it should be

used for the prototype. Also, the wing walls should not be placed at the downstream end of the stilling basin since they adversely affected flow conditions.

Extended entrance walls

27. After all tests of the low-stage structure were completed, the abutments to the drop structure were extended 50 ft upstream from the weir to determine what effect this would have on flow conditions in the stilling basin. Details of this modification (type 3) are shown in Plate 8. This design was not considered applicable for the South Fork Tillatoba Creek site modeled in this study but could possibly be considered for other projects. A structural advantage could be gained by moving the headwall and nonoverflow dike upstream from the weir to reduce the load on the walls of the weir crest. Also, the extended walls would result in more uniform flow passing over the weir. Riprap was placed between the extended walls for the initial tests. However, the riprap in this area failed, as shown in Photo 20, because of the high velocities. This area was then paved with concrete as shown in Photo 21. A scour test was conducted with the extended walls and the original design stilling basin. Results of these tests are shown in Photo 21 and Plate 15. The depth of scour was about the same as that with the type 2 abutments previously tested (compare scour in Plates 10 and 15).

High-Stage Structure

Approach area

28. Small eddies formed off the left approach dike in the approach area to the low-stage structure and moved into the entrance channel to the high-stage structure. A large, low-velocity eddy formed in the area to the right of the structure between the main levee and the spur dike. These eddies, shown in Photo 1, did not adversely affect flow entering the structure and no revisions were needed in the approach area to the high-stage structure.

Abutments

29. There was some contraction of flow at the abutments immediately upstream from the weir as shown in Photo 22. This caused concentration of flow into the center of the stilling basin and exit area as shown by the velocities in Plate 6. Several modifications to the abutments were tested in an attempt to reduce the flow contraction. These modifications included various lengths of rock dikes in the approach and various types of approach wing walls attached to the abutments (Plate 16). Approach wing walls that consisted of five 6-ft chords (type 6 design approach wing walls) were found to be the minimum length that effectively reduced contraction of flow (Photo 23). A slight discontinuity existed where the type 6 design approach wing walls tied into the levee, but this did not adversely affect flow conditions. Comparison of flow conditions at the design discharge with the original design abutment and the type 6 design approach wing walls can be made from Photo 24.

30. Scour tests were conducted with the original design abutments and with the type 6 design approach wing walls added to determine the effect of the wing walls on energy dissipation. The type 2 design crest, which will be discussed later, was in place for these tests. Scour resulting with the original abutments is shown in Photo 25 and Plate 17. Scour resulting with the wing walls added is shown in Photo 26 and Plate 17. Comparison of these test results shows less scour with the wing walls in place.

Stilling basin

31. The stilling basin in the high-stage structure was designed for an 8-ft-head on the weir; therefore, the basin was only 41 ft long. Flow conditions with the original design basin and 14,800 cfs are shown in Photo 27. A hydraulic jump was maintained in the basin with all expected discharge and tailwater conditions. Results of a scour test conducted with this basin are shown in Plate 17. The scour pattern was not symmetrical. A large buildup of sand formed on the right side of the exit channel as shown in Photo 28. The maximum depth of scour was 12 ft, which occurred at the downstream edge of the preformed scour

hole. Sand did not deposit in the area of the riprap channel side slopes, indicating less severe eddies than were observed with the low-stage structure.

32. Although the stilling basin as originally designed functioned satisfactorily, a curved trajectory was added to the weir in an effort to further improve energy dissipation. The short length of the basin restricted the use of the equation $X^2 = 40Y$ as had previously been tested for the low-stage structure. Thus, a curve based on the parabolic equation $X^2 = 20Y$ was arbitrarily chosen. This was designated the type 2 design crest shown in Plate 18. Some improvement of flow conditions was achieved with this modification. Flow conditions in the stilling basin with the design discharge are shown in Photo 29. Scour tests results obtained with this design are shown in Photo 25 and Plate 17. Scour was greatly reduced by the addition of the curved trajectory (compare Photos 25 and 28). The maximum depth of scour was reduced from 12 to 4 ft.

33. Although the type 2 design crest improved flow conditions and reduced scour depths, it would add considerably to construction cost of the prototype structure because of the long weir. Also, the occurrence of large flows over the high-stage structure is very infrequent. For these reasons, the sponsor did not consider the curved drop to be economically justified. Subsequent tests were conducted with the original weir.

Riprap protection plan

34. The original riprap plan is shown in Plate 1 and Photo 30. The average diameter (D_{50}) of the riprap was 12 in. and the blanket was 18 in. thick; gradation of the riprap is shown in Plate 14. Riprap upstream from the structure was grouted because of the high velocities immediately upstream from the weir. Also, the riprap on the slope into the preformed scour hole immediately downstream from the stilling basin was grouted. The riprap remained stable throughout several tests where flood hydrographs with a peak discharge of 14,800 cfs were simulated.

35. Although the downstream protection plan was stable, changes to the exit channel (discussed subsequently) resulted in changes to the

original riprap plan. The preformed scour hole was eliminated since it appeared to concentrate flow toward the center of the exit channel. The type 2 design riprap plan shown in Plate 18 was 27 ft longer than the original plan, since it extended the full distance of the replaced scour hole. The riprap size, thickness, and gradation were not changed. None of the riprap in the downstream area was grouted. The riprap remained stable throughout a test conducted with the flood hydrograph.

Exit channel

36. Flow conditions in the exit channel of the high-stage structure with the normal tailwater, el 234.3, and the tailwater expected with the ultimately degraded channel, el 233.0, are shown in Photo 27. Eddies in the exit channel were more intense on the left side (looking downstream) for both tailwaters but were not as strong as those observed in the low-stage structure exit channel.

37. In an effort to reduce the eddies and save on excavation costs, the bottom width of the exit channel was reduced from 185 to 141 ft and the preformed scour hole was eliminated. The downstream wing walls were not removed from the structure since they were needed as retaining walls for the levee. These modifications are shown in Photo 31 and Plate 19. Flow conditions were improved with the modified channel as shown in Photo 32. Results of a scour test conducted with the modified channel and the type 2 design riprap plan are shown in Photo 33 and Plate 17. The maximum depth of scour was 4 ft. Since the modified channel improved flow conditions and would be less costly to construct, it should be used for the prototype.

Final Tests

38. After all of the recommended modifications were made to both structures, final tests were conducted to obtain a discharge calibration, document flow conditions, and measure velocities in various areas throughout the model. Modifications to the low-stage structure included reducing the length of the right spur dike from 125 to 25 ft, adding the type 7 design approach wing walls, adding the type 4 design

crest, removing the downstream wing walls, and reducing the bottom width of the exit channel from 80 to 39 ft. Modifications to the high-stage structure included the type 6 design approach wing walls, the type 2 design riprap plan, and reduction of the exit channel width from 185 to 141 ft.

39. A discharge calibration curve is shown in Plate 4. Modifications increased the efficiency of the structures with higher discharges as can be seen by comparing the curves in Plate 4.

40. Velocities measured in the approach and exit areas with the design discharge are shown in Plates 20 and 21. Flow conditions for the peak discharge from the 50-year frequency storm (8,800 cfs) and the design discharge (14,800 cfs) are shown in Photos 6, 32, and 34-37.

PART IV: CONCLUSIONS

41. Approach flow into the low-stage structure was improved by shortening the right approach dike. This eliminated the formation of eddies that caused unequal distribution of flow into the stilling basin. No changes were made to the left approach dike.

42. The original design (square) abutments at the entrance to the low-stage stilling basin caused concentration of flow in the center of the stilling basin that adversely affected energy dissipation. Rounding the abutments reduced this concentration of flow. Approach wing walls were found to be even more effective in uniformly distributing flow across the basin.

43. A trajectory curve was added downstream from the weir crest of the low-stage structure to stabilize the nappe and increase the effective length of the stilling basin. The curve caused flow to plunge into the stilling basin with higher tailwater elevations. This will be very beneficial for this project because of the highly submerged tailwater conditions during high flows. Tests showed that the length of the stilling basin and the baffle block and end sill size and location were satisfactory as originally designed.

44. The riprap protection plan for the low-stage structure was satisfactory. No movement of the riprap was observed during normal operations. Smaller riprap was not tested since the sponsor did not think it practical to place riprap smaller than 12 in. (D_{50}) in the prototype.

45. The wing walls at the downstream end of the low-stage structure were removed because they intensified the eddies that formed in the exit channel. The bottom width of the exit channel was reduced while the same slope of the sides was maintained. This reduced the severity of the eddies by eliminating some of the area where they formed. These modifications improved flow conditions and did not cause additional scour or attack to the channel slopes, and should result in considerably less excavation and construction costs in the prototype.

46. Contraction of flow at the abutments to the high-stage

structure was reduced by the addition of approach wing walls. These walls helped distribute flow across the weir and resulted in better energy dissipation in the stilling basin.

47. The stilling basin for the high-stage structure functioned satisfactorily as originally designed. However, a curved trajectory placed downstream from the weir crest was found to improve flow conditions and increase energy dissipation. This modification would probably add considerably to the construction costs. Since large flows over this structure occur infrequently, and scour downstream from the structure was not excessive with the original design, the curved trajectory may not be justified.

48. The preformed scour hole downstream from the high-stage structure stilling basin was eliminated because it concentrated flow toward the center of the exit channel. The flat riprap plan developed for this area was stable and the additional length reduced the amount of scour to be expected with the original design stilling basin.

49. The exit wing walls were not removed from the high-stage structure because they were needed as retaining walls for the levee. Reducing the exit channel width reduced the intensity of eddies that formed downstream from the structure.

50. The two structures were more efficient in passing flow, especially with higher discharges, after the discussed modifications were made. The structures, with the modifications recommended in this study, should perform satisfactorily for all discharge and tailwater combinations anticipated. Some scour can be expected in the areas downstream from the riprap protection after several hours of operation with large flows. However, this scour should be minimal, and should not endanger the integrity of the structures.

Table 1

Explanation of Major Modifications to South Fork Tillatoba Creek Drop Structures

Low-Stage Structure	
Type 2 Abutments	3-ft-radius curve placed on the entrance walls
Type 3 Abutments	Existing stilling basin walls extended 50 ft upstream of the weir crest with a 3-ft-radius curve at entrance
Type 3 Crest Shape	Crest shaped to the equation $X^2 = 40Y$ (This was the optimum parabolic shape determined from tests conducted on low-head navigation structures)
Type 4 Crest Shape	Crest shaped to the equation $X^2 = 72Y$ (The theoretical equation for a free trajectory using Tillatoba parameters)
Type 7 Approach Wing Walls	Wing wall with four 8-ft chords simulating a 20-ft radius
Type 2 Baffle Block Design	Two rows of baffle blocks, each block 5.5 ft high by 3.0 ft wide, with a 2-ft flat portion on top of the block and a 1V-on-1H sloping downstream face
Exit Channel Bottom Width	Reduced from 80 to 39 ft, and exit wing walls removed
High-Stage Structure	
Type 2 Crest Shape	Crest shaped to the equation $X^2 = 20Y$
Type 6 Approach Wing Walls	90-deg wing wall with five 6-ft-long chords
Type 2 Riprap Plan	Riprap plan consisting of the same size stone as the original design but placed starting 2 ft below the end sill and sloping upward until tying into the downstream channel at el 221
Exit Channel Bottom Width	Reduced from 185 to 141 ft

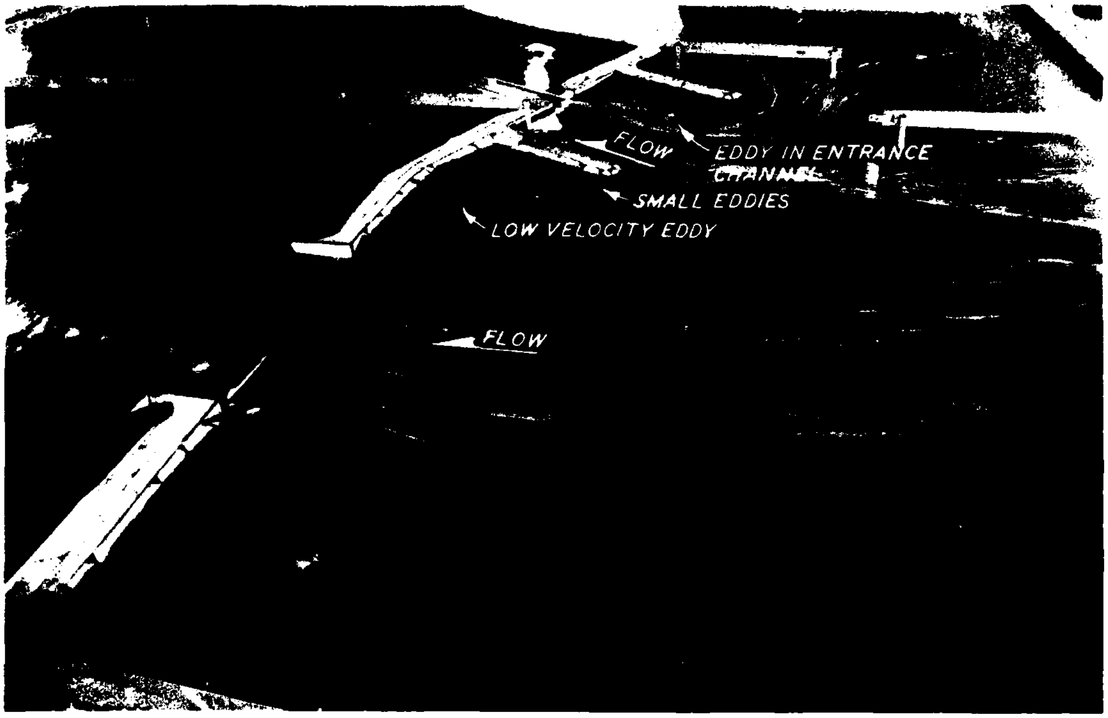


Photo 1. Flow conditions with the original design; discharge 14,800 cfs, tailwater el 234.3. Confetti accents surface flow patterns; exposure time 15 sec prototype

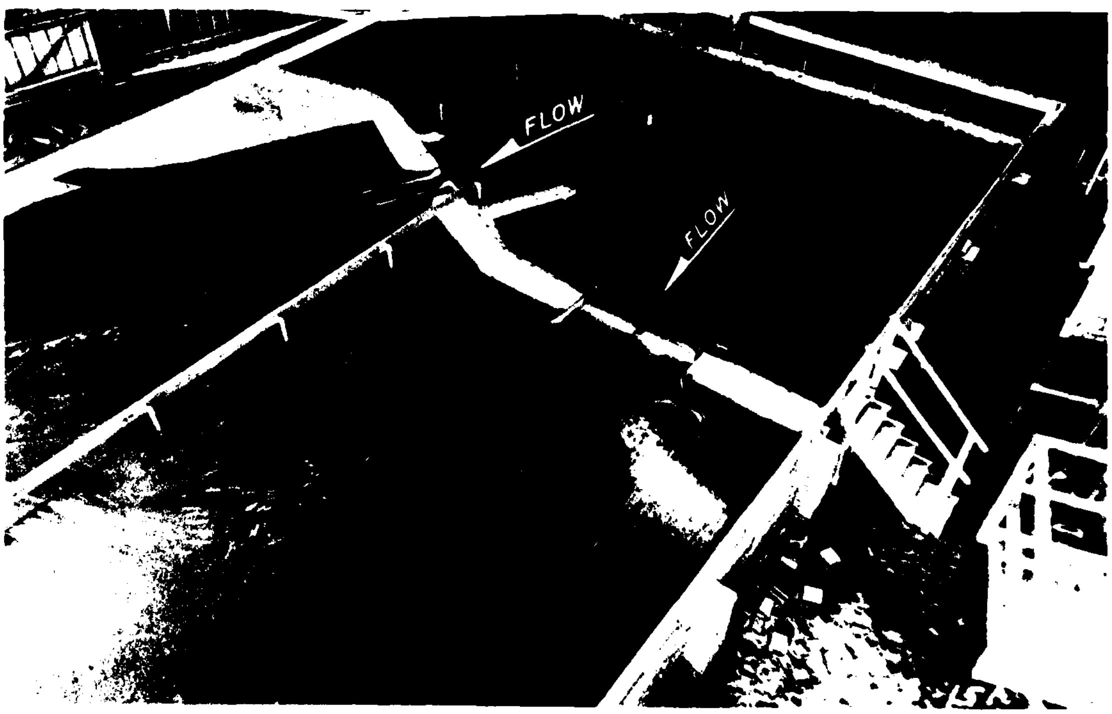
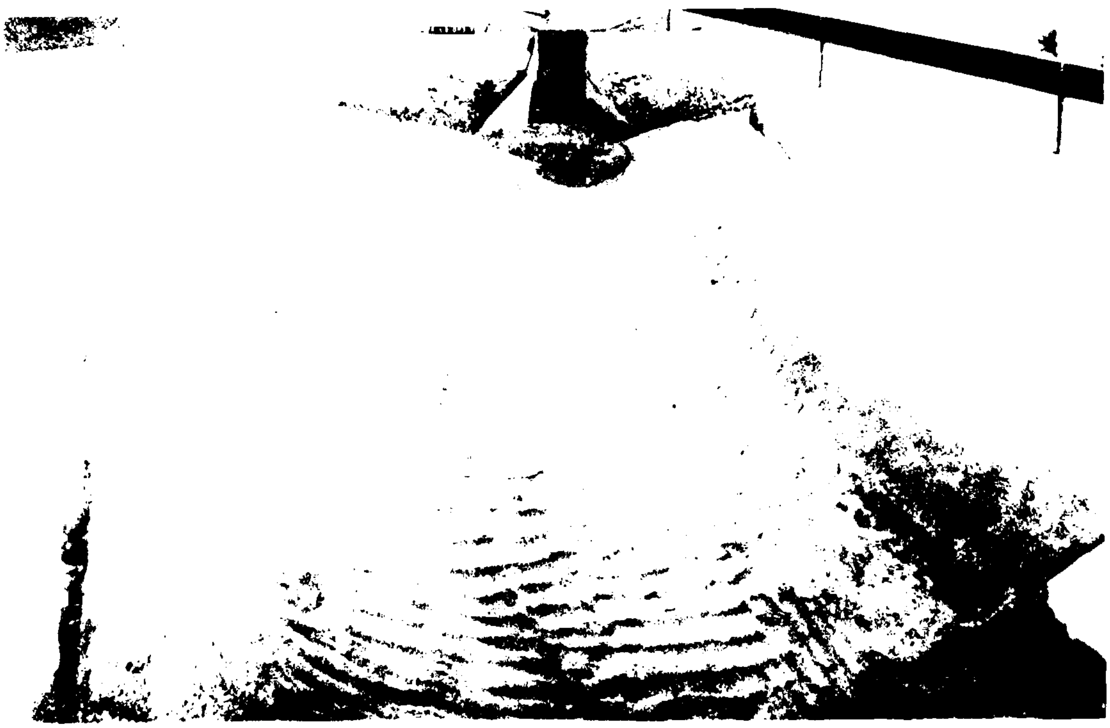


Photo 2. Flow conditions with length of right approach dike reduced; discharge 14,800 cfs, tailwater el 234.3

Photo 3. Flow conditions with square abutments; discharge 14,800 cfs, tailwater el 234.3

a. Looking downstream



b. Looking upstream

Photo 4. Scour in exit channel of low-stage structure with original design stilling basin

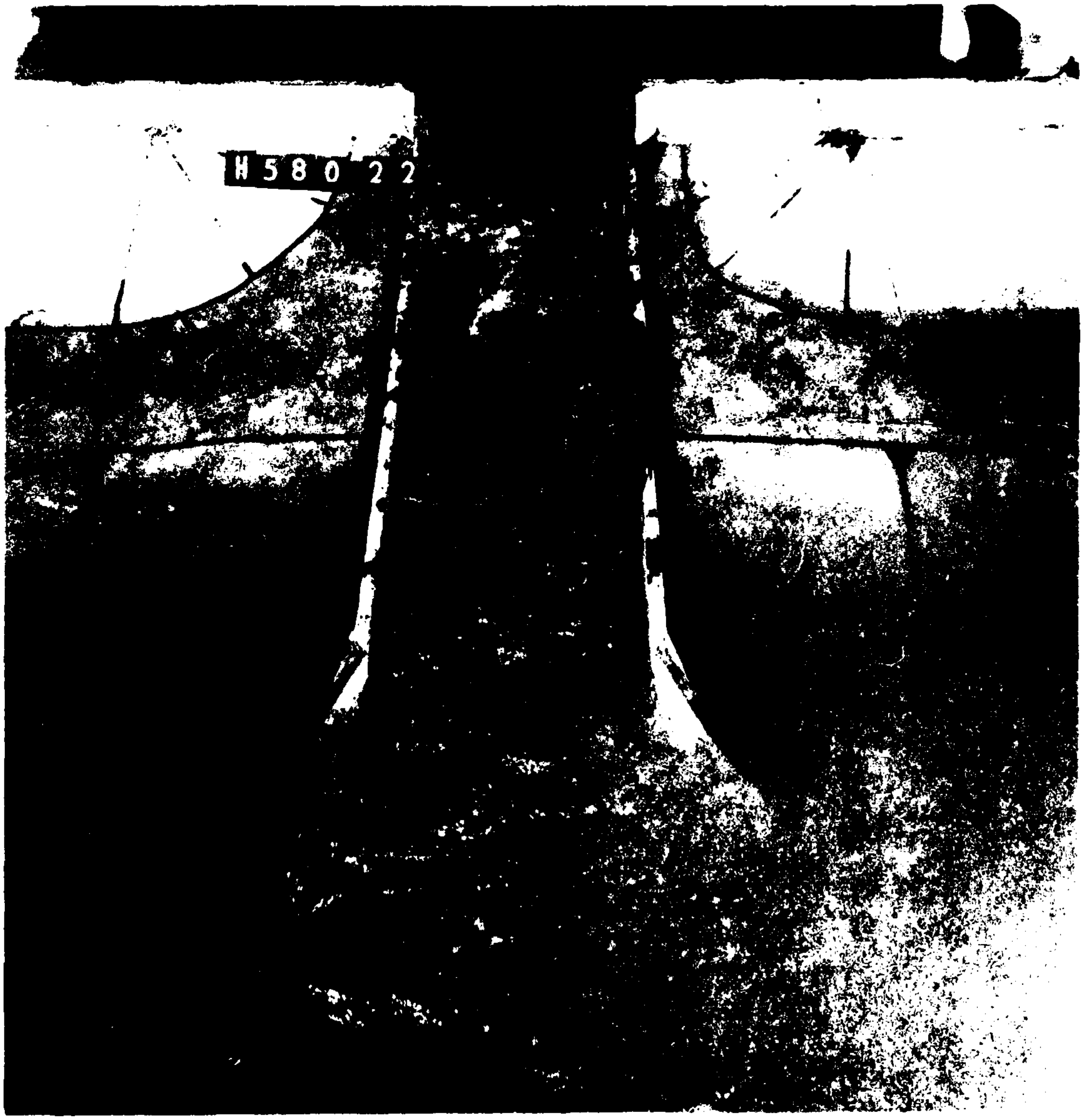


Photo 5. Flow conditions with type 2 design abutments; discharge 14,800 cfs, tailwater el 234.3

a. Existing tailwater el 234.3

b. Tailwater el 233.0 with ultimate degraded channel conditions

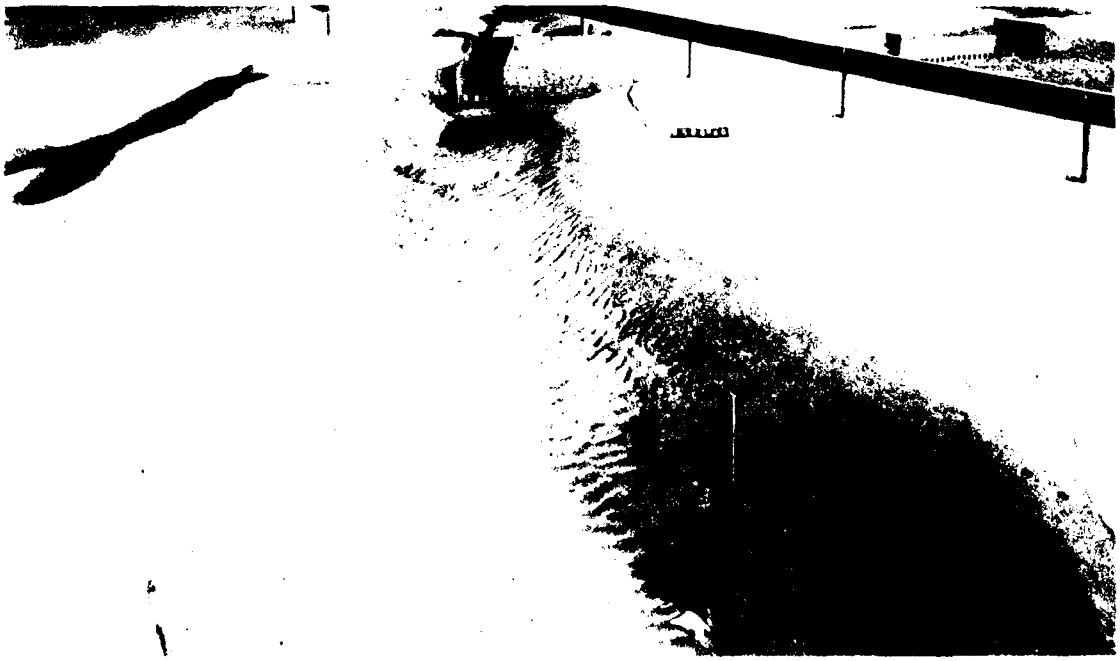
Photo 6. Flow conditions with type 7 design approach wing walls, type 4 design crest, and reduced bottom width in exit channel of low-stage structure for design discharge of 14,800 cfs

a. Looking downstream

b. Looking upstream

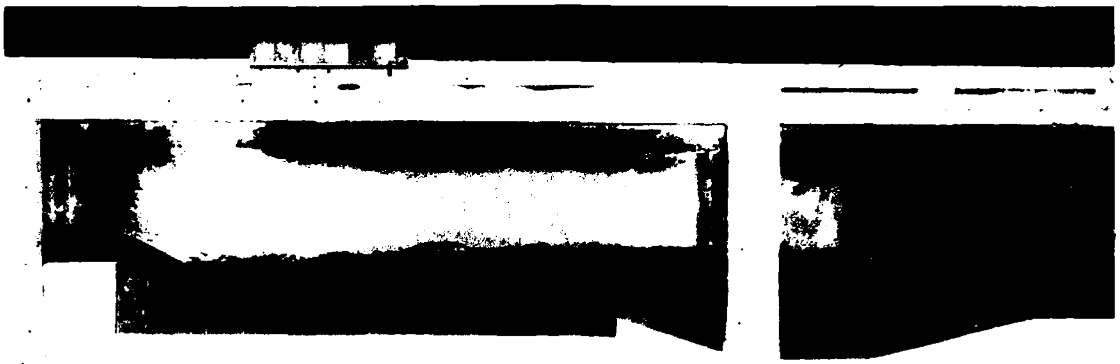
Photo 7. Scour in modified exit channel of low-stage structure with type 2 design abutments

a. Looking downstream

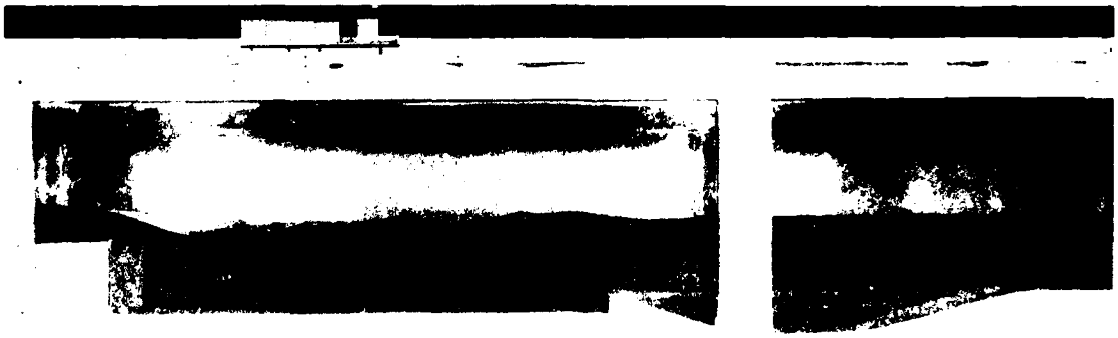


b. Looking upstream

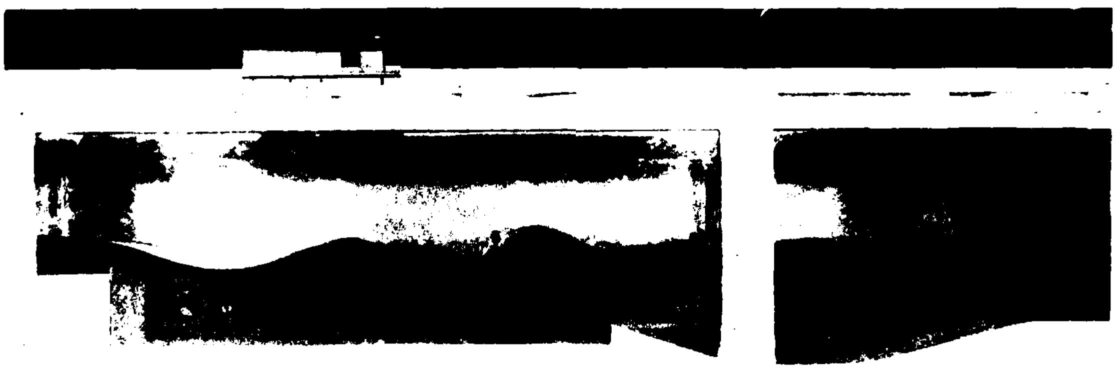
Photo 8. Scour in modified exit channel of low-stage structure with type 7 design approach walls



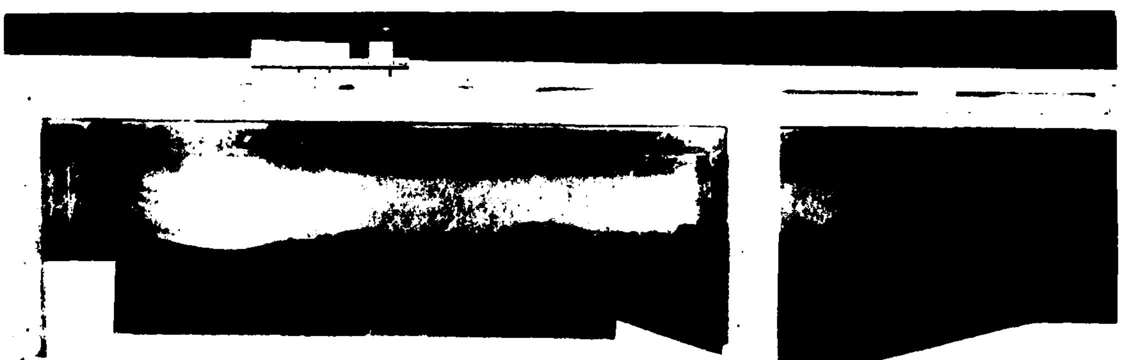
a. GOOD HYDRAULIC JUMP, TAILWATER EL 224.7



b. TAILWATER EL 227.0



c. FLOW RIDING THROUGH BASIN, TAILWATER EL 228.0



d. TAILWATER EL 230.0

Photo 9. 1:29-scale section model of original design low-stage structure stilling basin; discharge 3,100 cfs

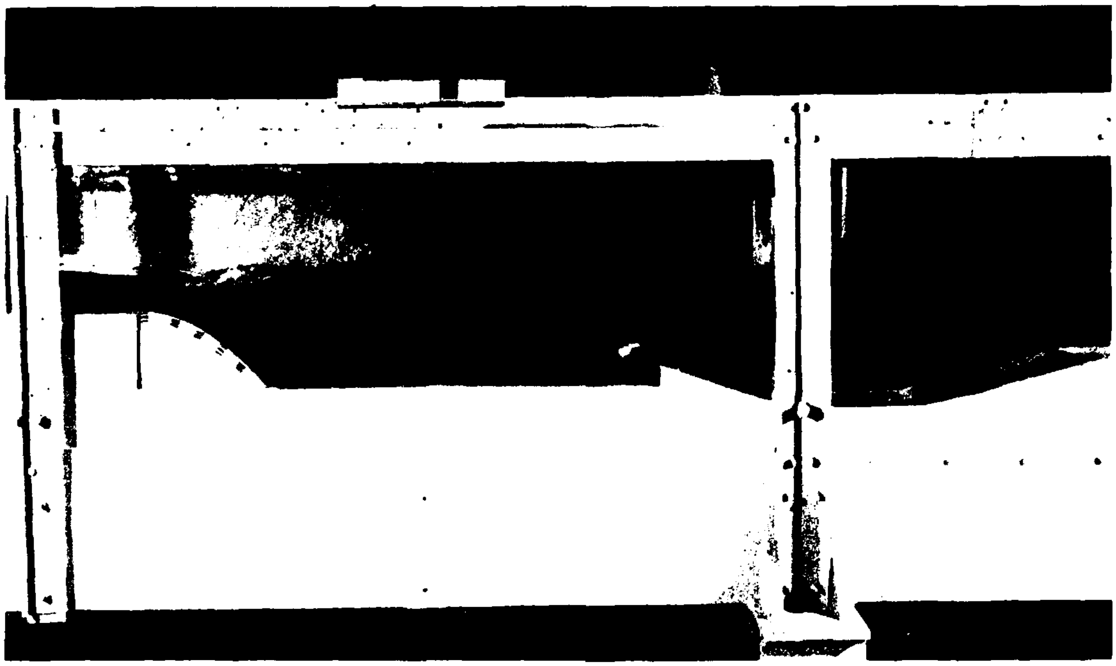


Photo 10. 1:29-scale section model of low-stage structure with type 3 design crest; discharge 3,100 cfs, tailwater el 228.0

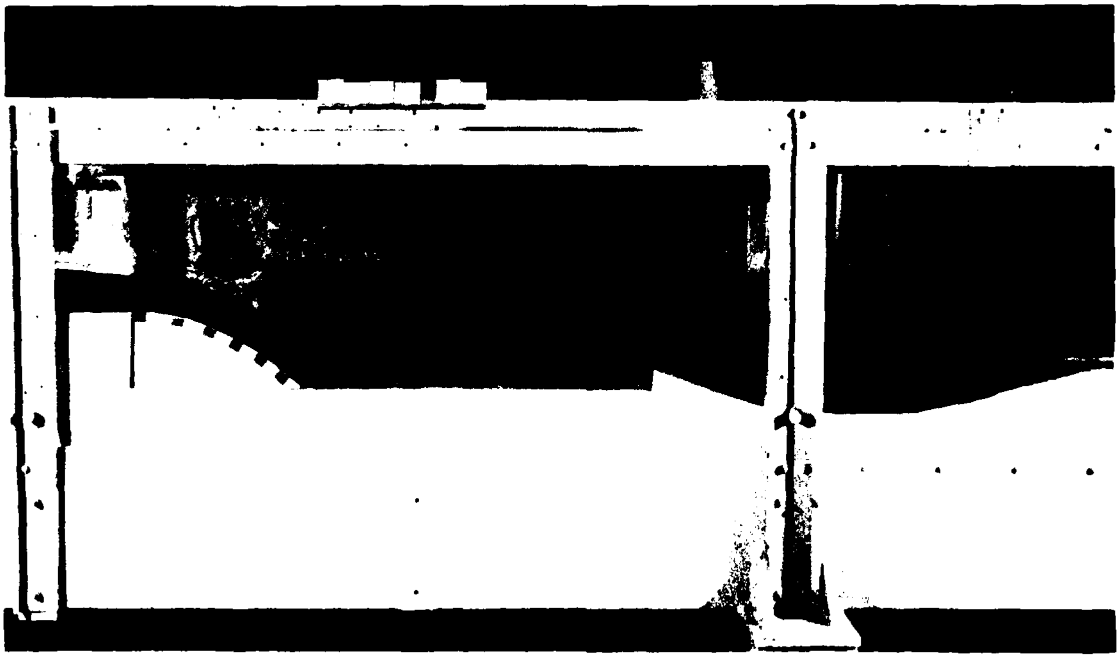
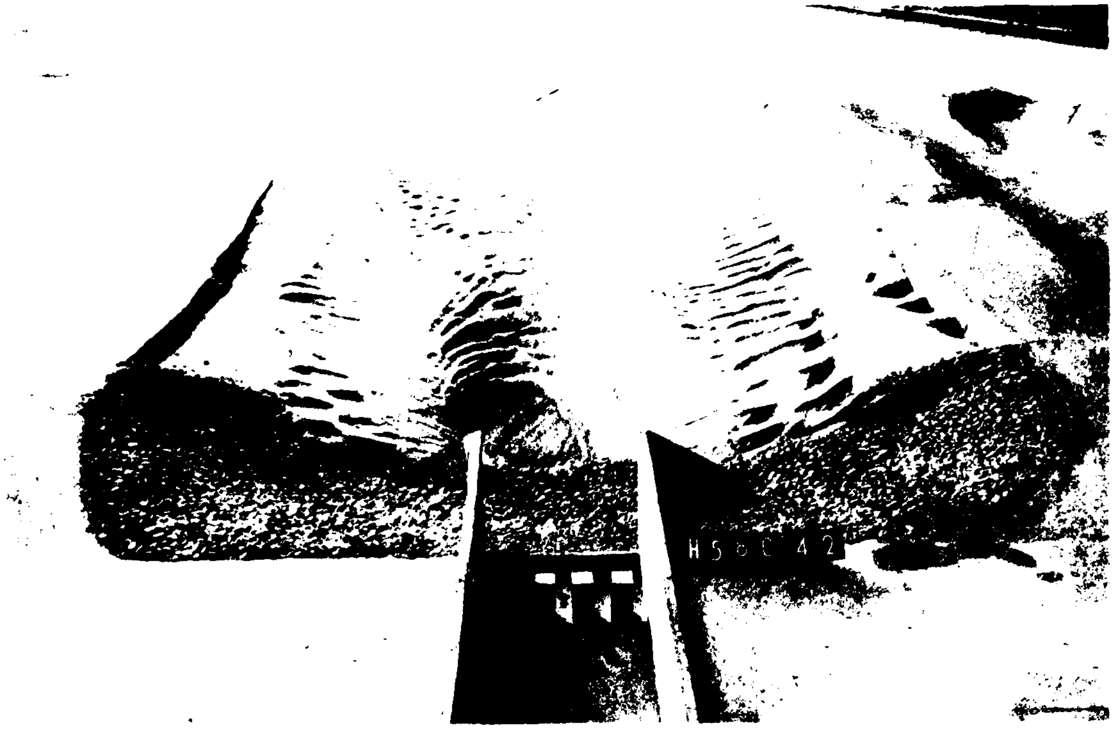
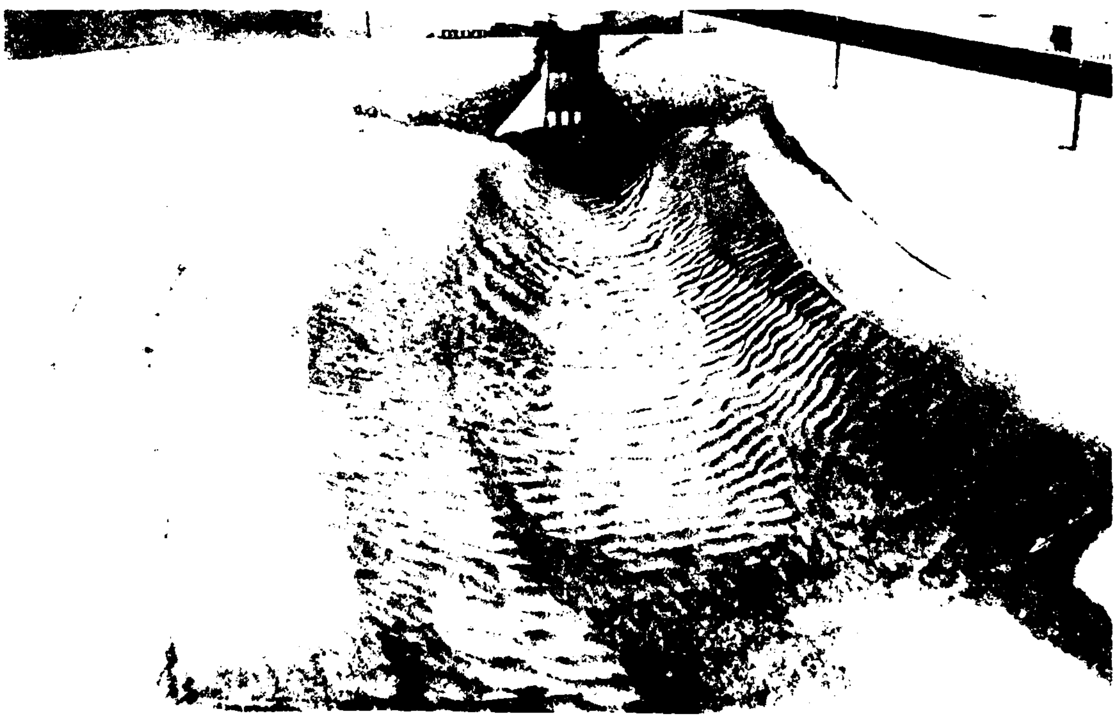


Photo 11. 1:29-scale section model of low-stage structure with type 4 design crest; discharge 3,100 cfs, tailwater el 228.0

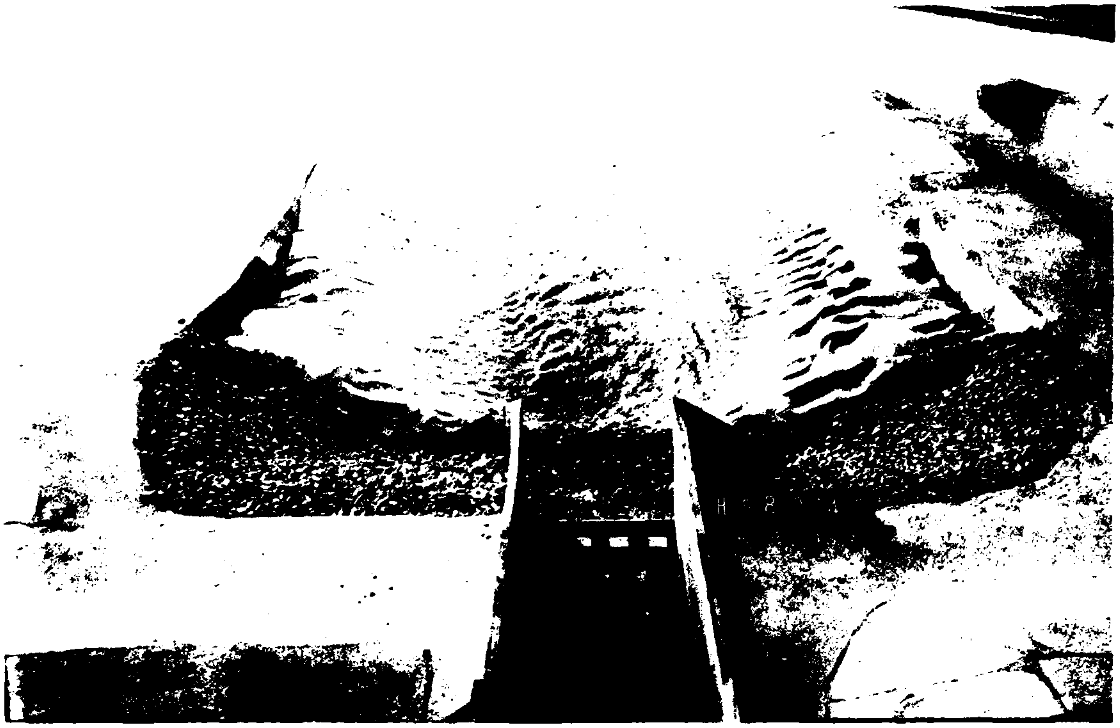


a. Looking downstream

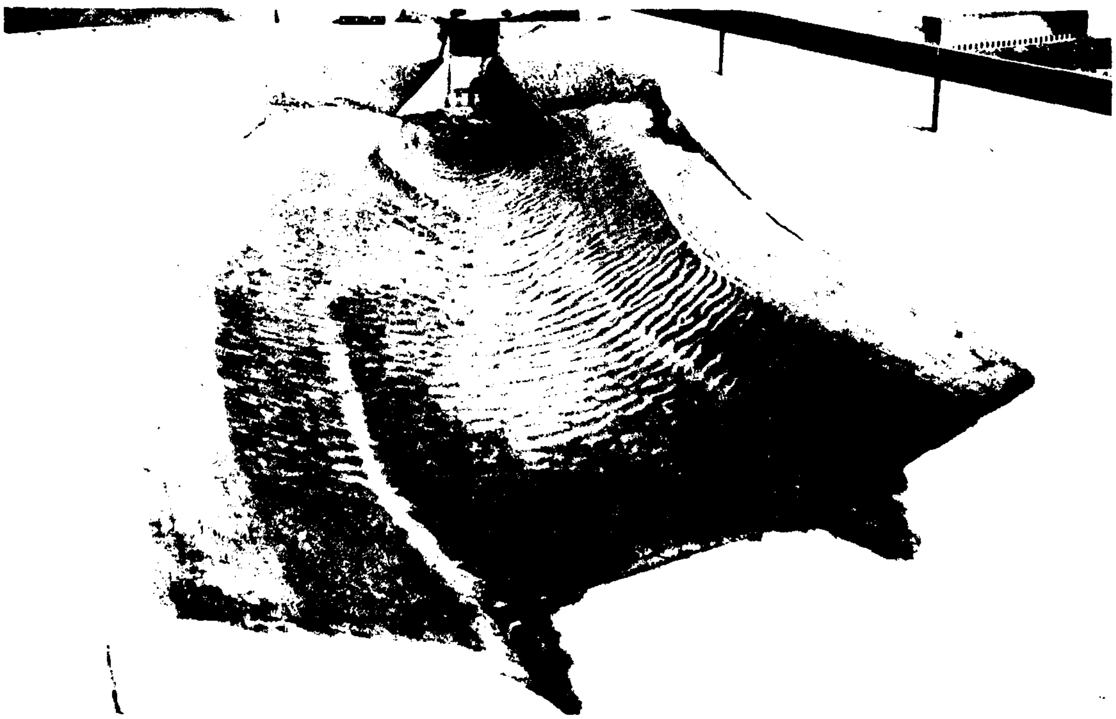


b. Looking upstream

Photo 12. Scour in exit channel of low-stage structure with type 2 abutments and type 3 design crest in stilling basin

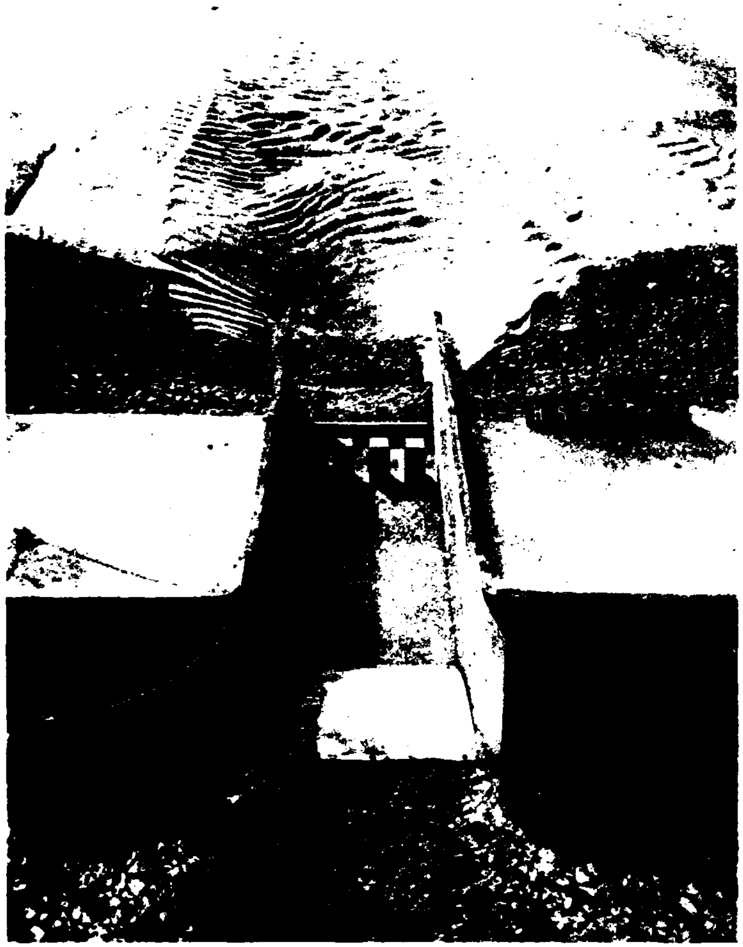


a. Looking downstream



b. Looking upstream

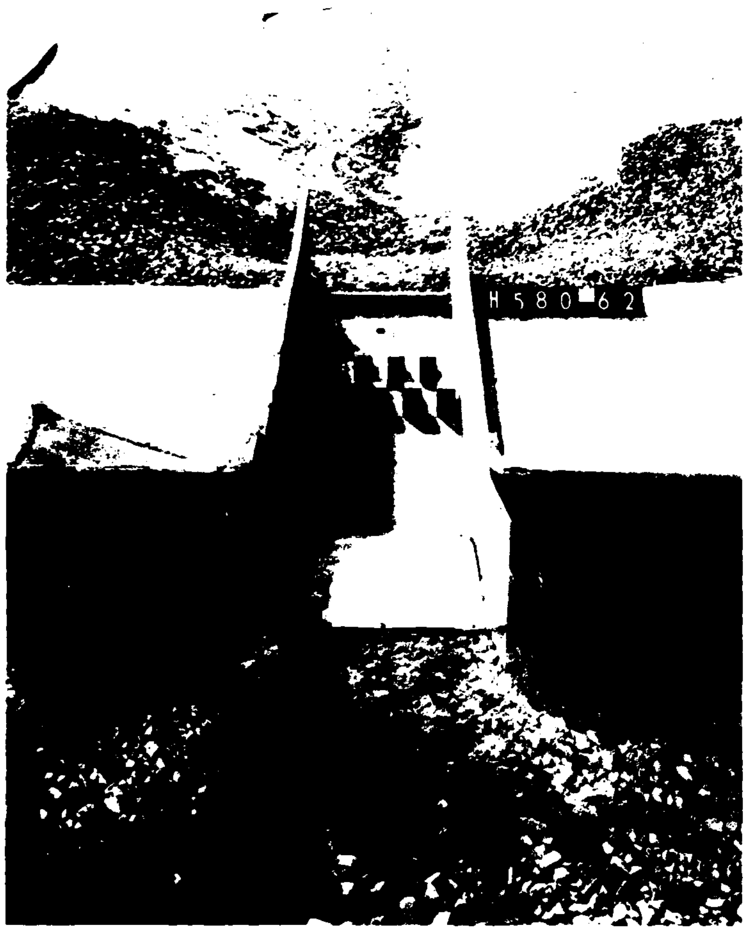
Photo 13. Scour in exit channel of low-stage structure with type 2 abutments and type 4 design crest in stilling basin



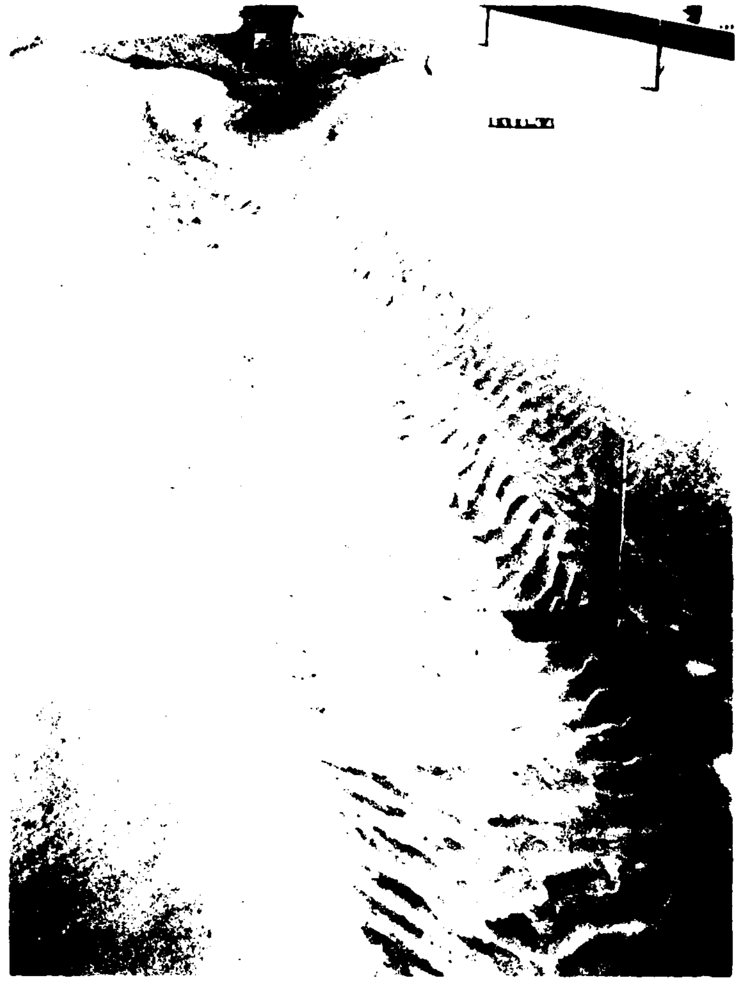
a. Looking downstream

b. Looking upstream

Photo 14. Scour in modified exit channel of low-stage structure with type 7 design approach walls and type 4 design crest in stilling basin

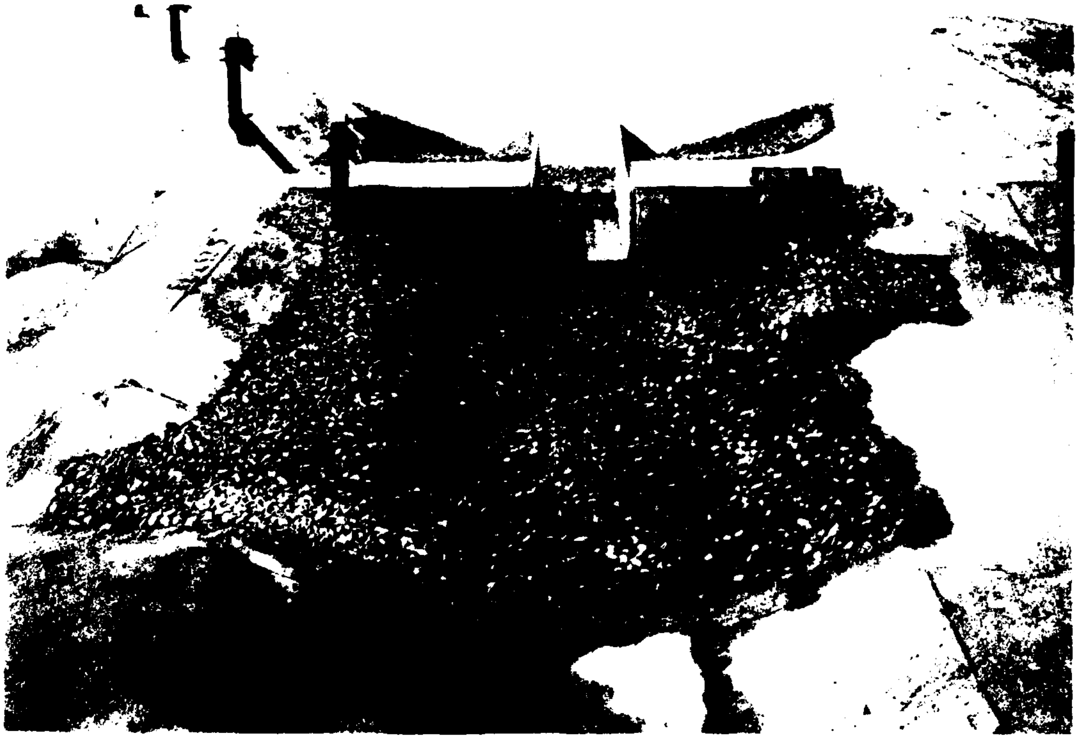


a. Looking downstream

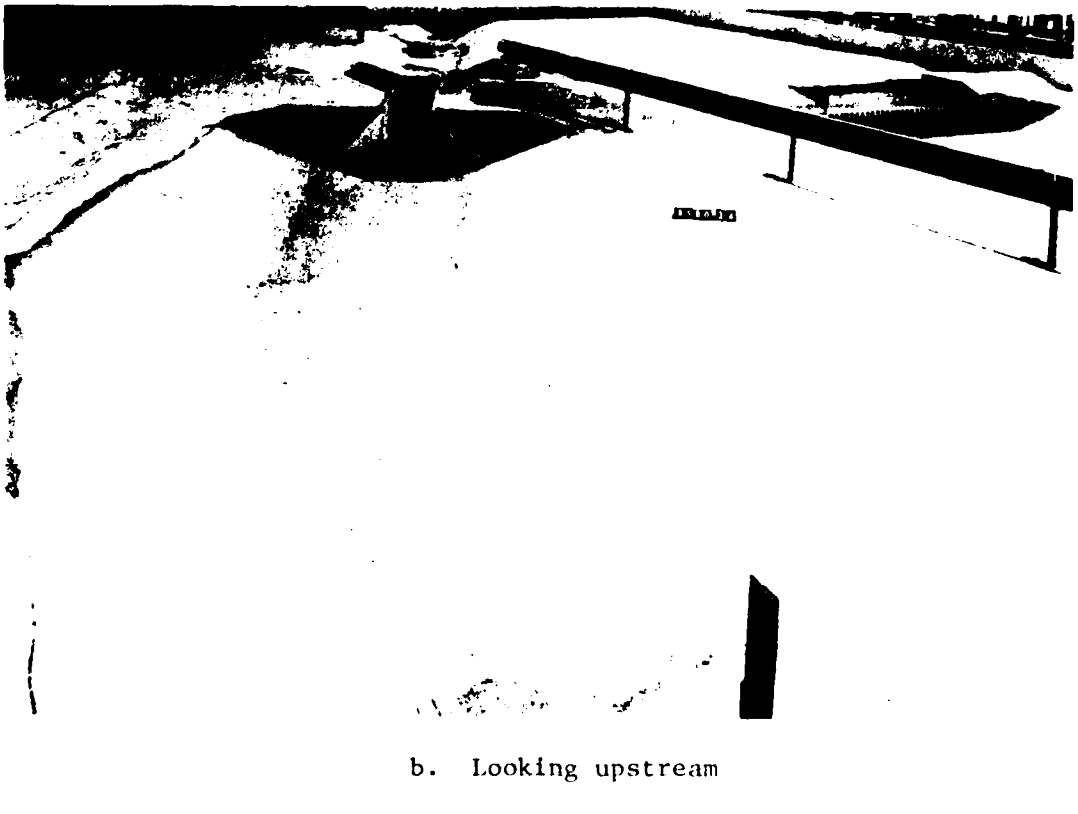


b. Looking upstream

Photo 15. Scour in modified exit channel of low-stage structure with type 7 design approach wing walls, type 4 design crest, and type 2 baffle block design in stilling basin



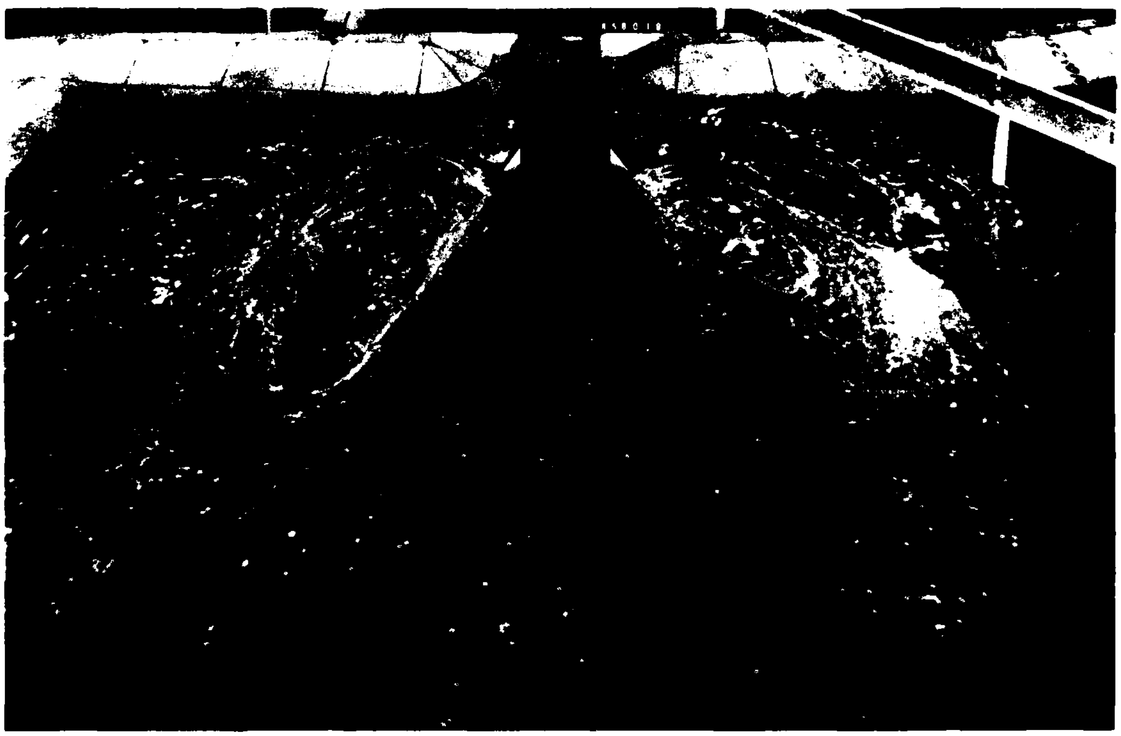
a. Looking downstream



b. Looking upstream

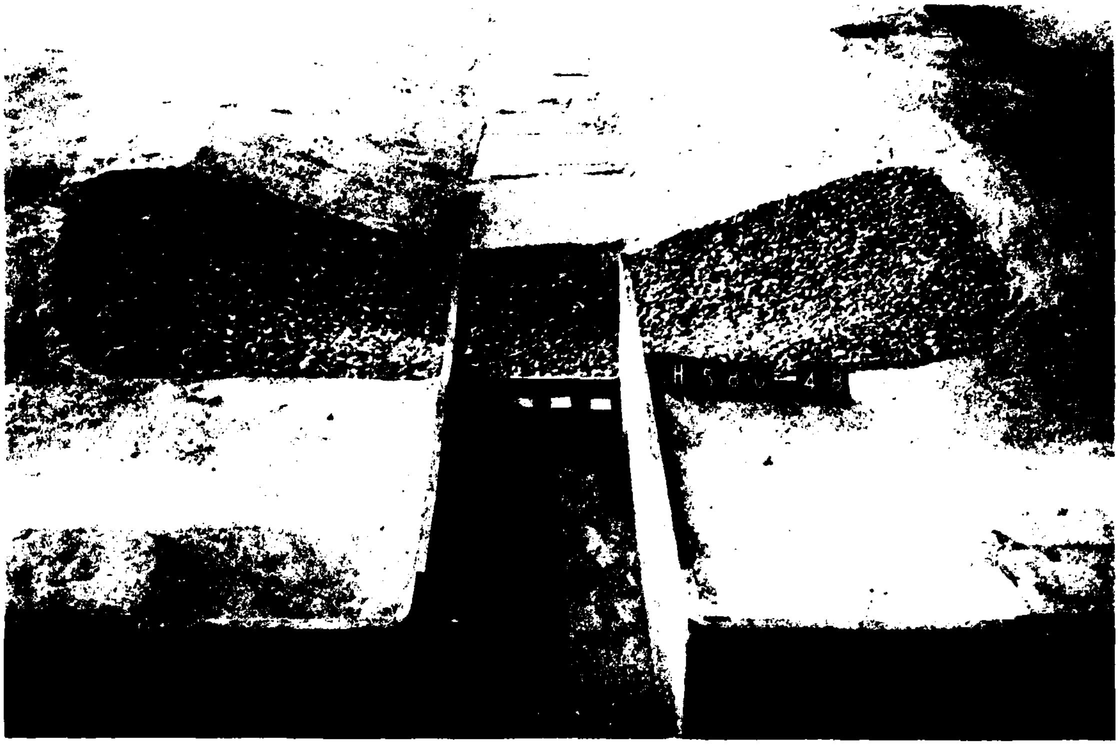
Photo 16. Low-stage structure riprap protection plan

a. Existing tailwater el 234.3



b. Tailwater with ultimate degraded channel conditions, el 233.0

Photo 17. Looking upstream at flow conditions in exit channel of low-stage structure (original design); discharge 14,800 cfs

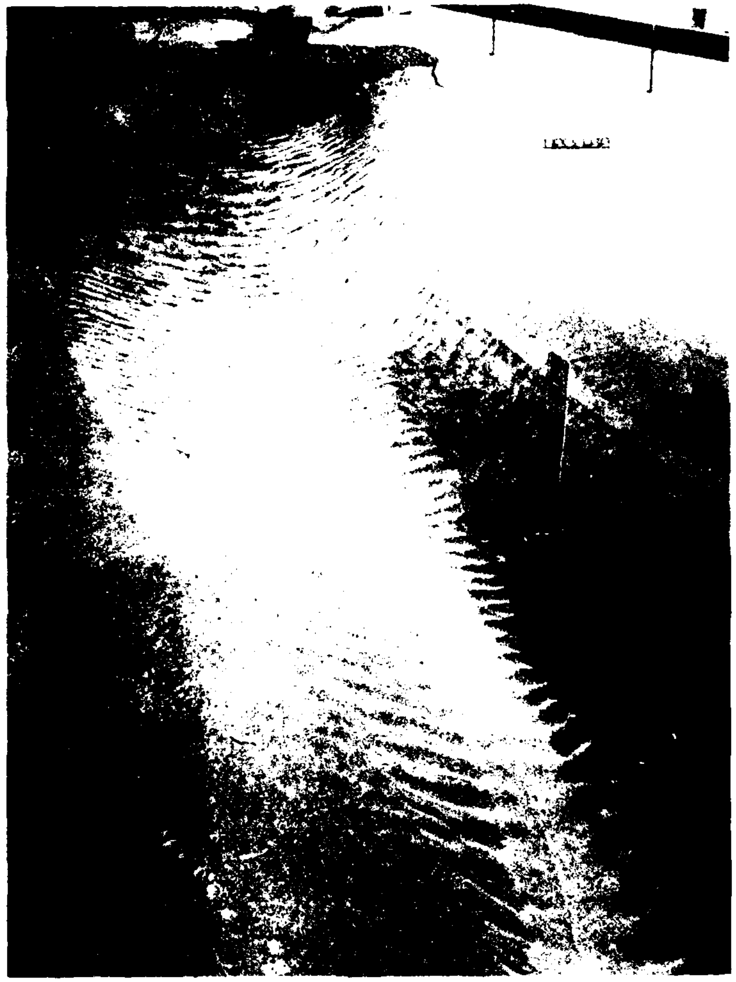


a. Looking downstream

b. Looking upstream

Photo 18. Low-stage structure with reduced bottom width in exit channel and exit wing walls removed

a. Looking downstream

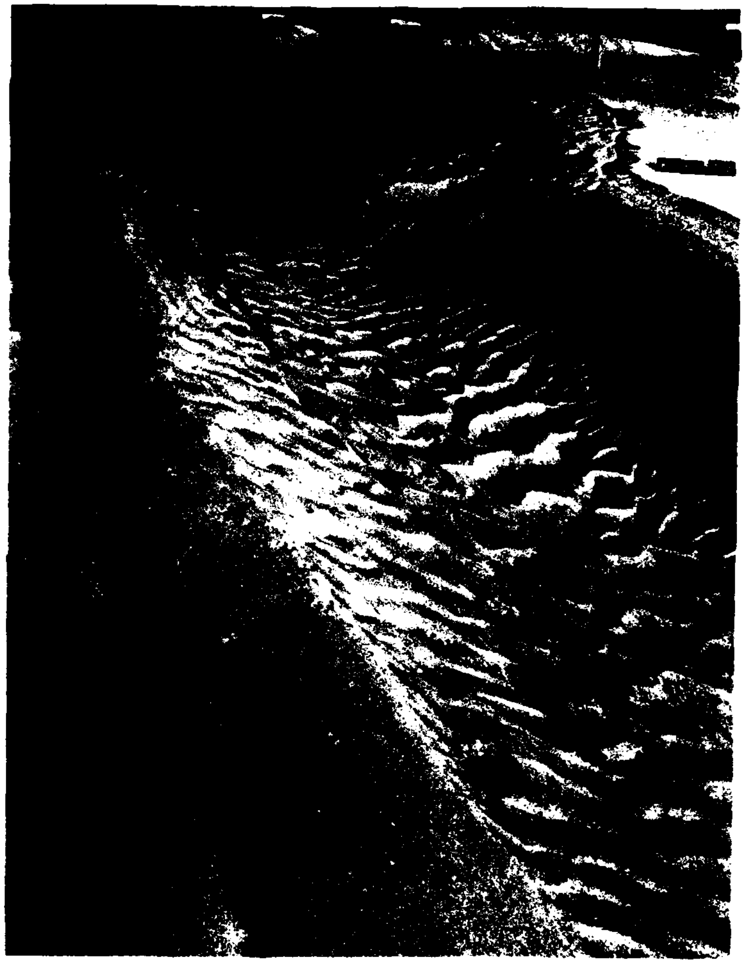


b. Looking upstream

Photo 19. Scour in modified exit channel of low-stage structure with type 2 abutments and type 4 design crest in stilling basin

Photo 20. Scour in area between extended entrance walls

a. Looking downstream



b. Looking upstream

Photo 21. Scour in modified exit channel of low-stage structure with type 3 abutments

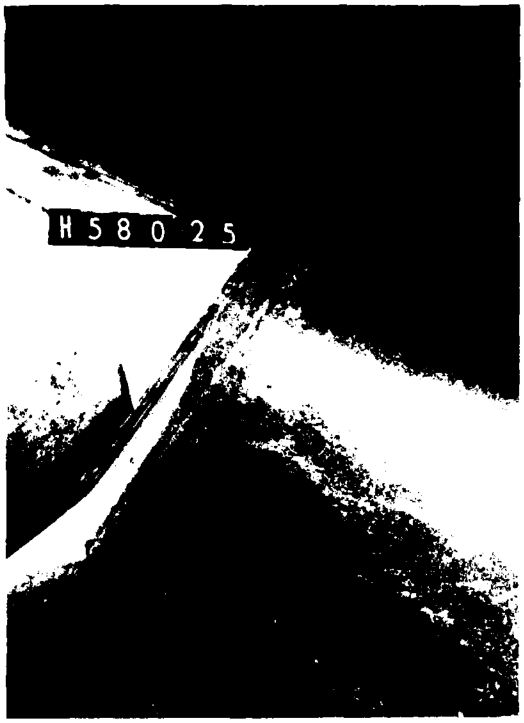


Photo 22. Flow contraction at abutment; discharge 14,800 cfs

Photo 23. Flow conditions with type 6 design approach wing wall; discharge 14,800 cfs

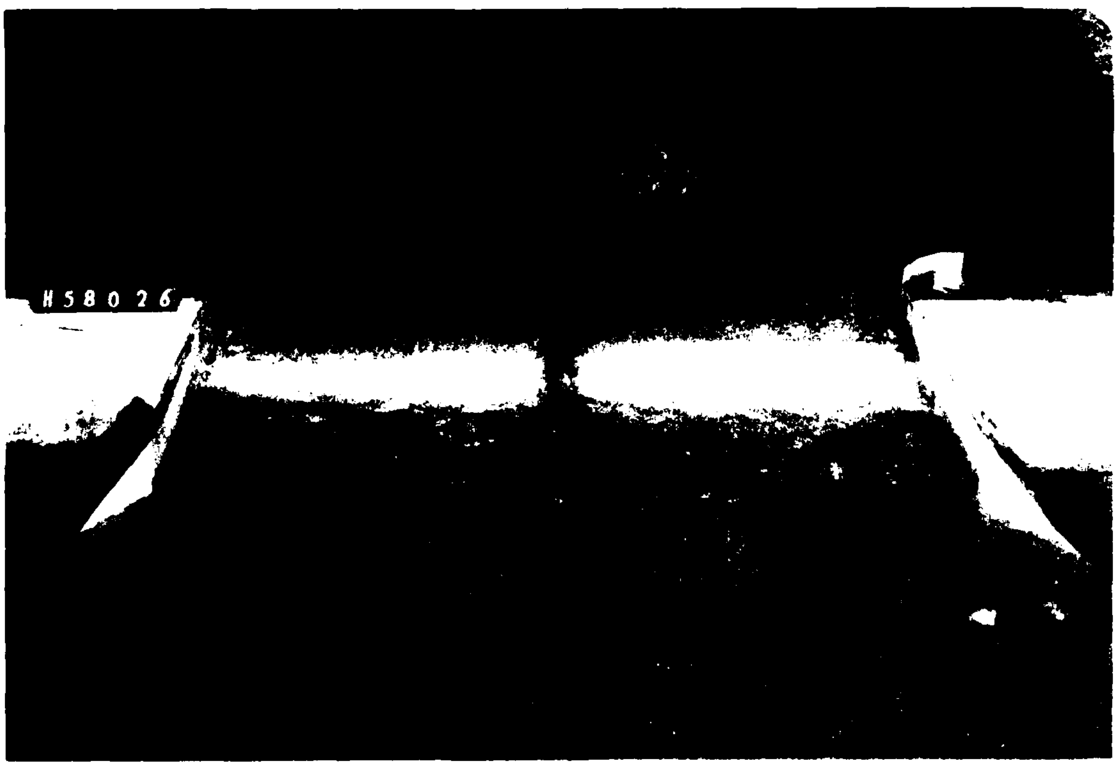
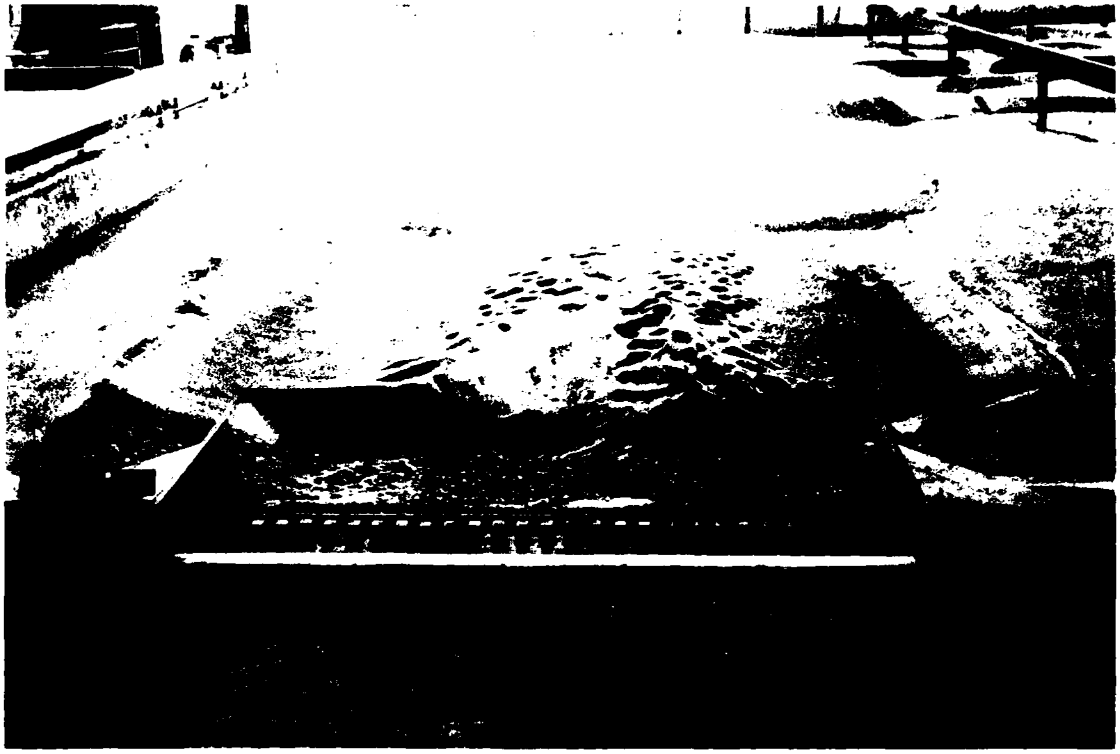


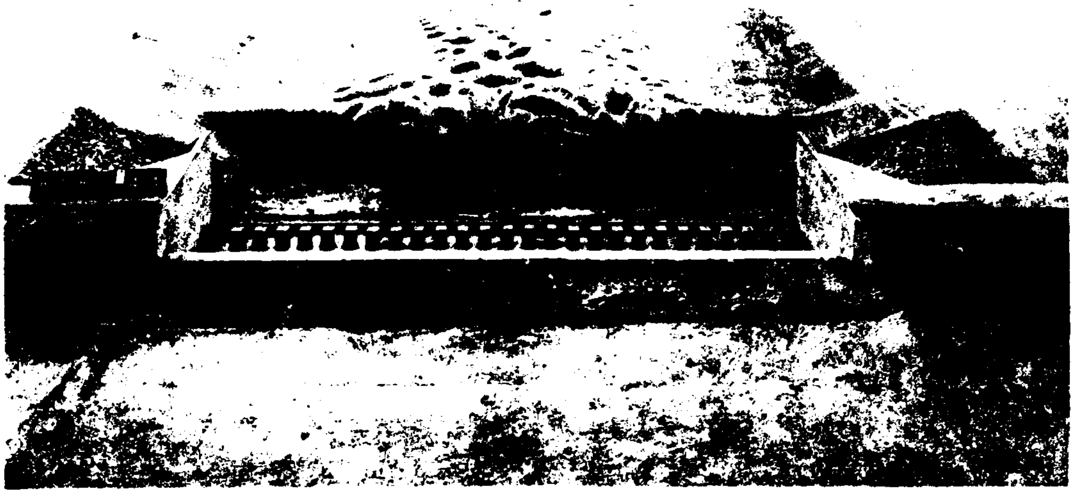
Photo 24. Comparison of designs; discharge 14,800 cfs



a. Looking downstream

b. Looking upstream

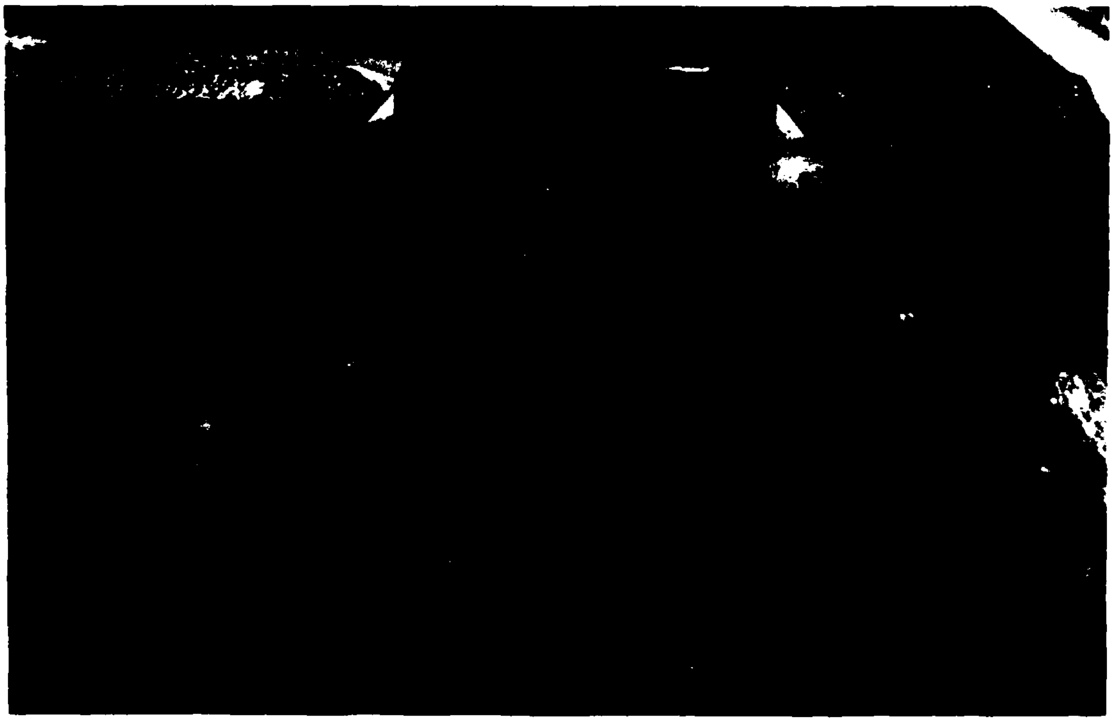
Photo 25. Scour in exit channel of high-stage structure with type 2 design crest in stilling basin



a. Looking downstream

b. Looking upstream

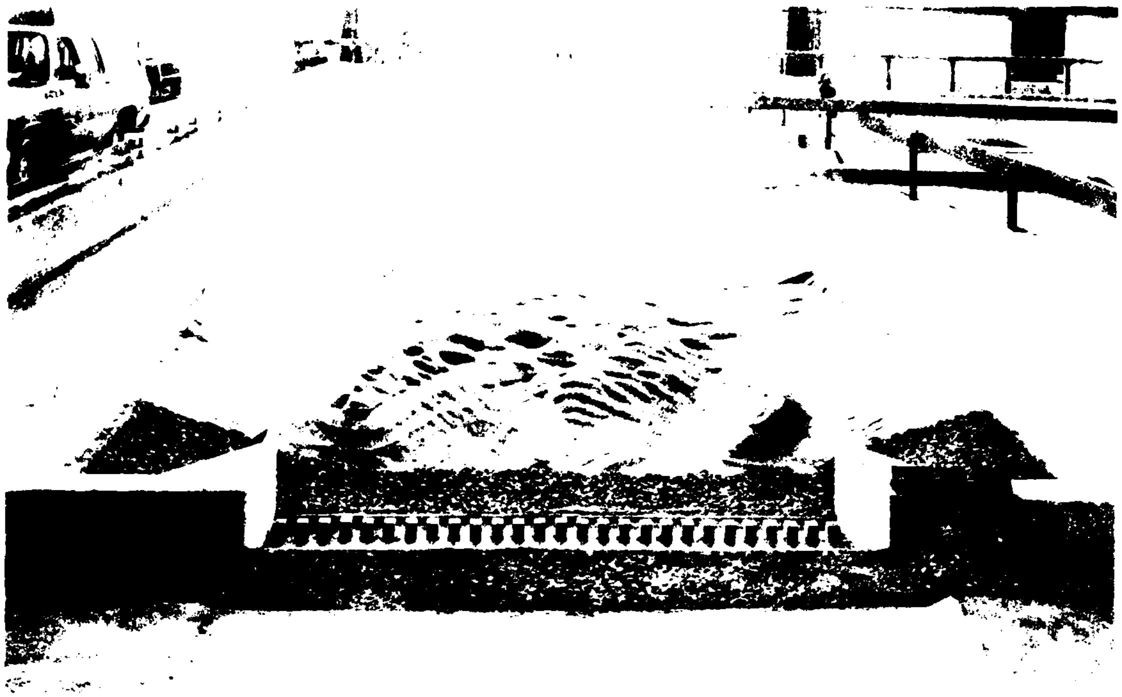
Photo 26. Scour in exit channel of high-stage structure with type 6 design approach wing walls and type 2 design crest in stilling basin



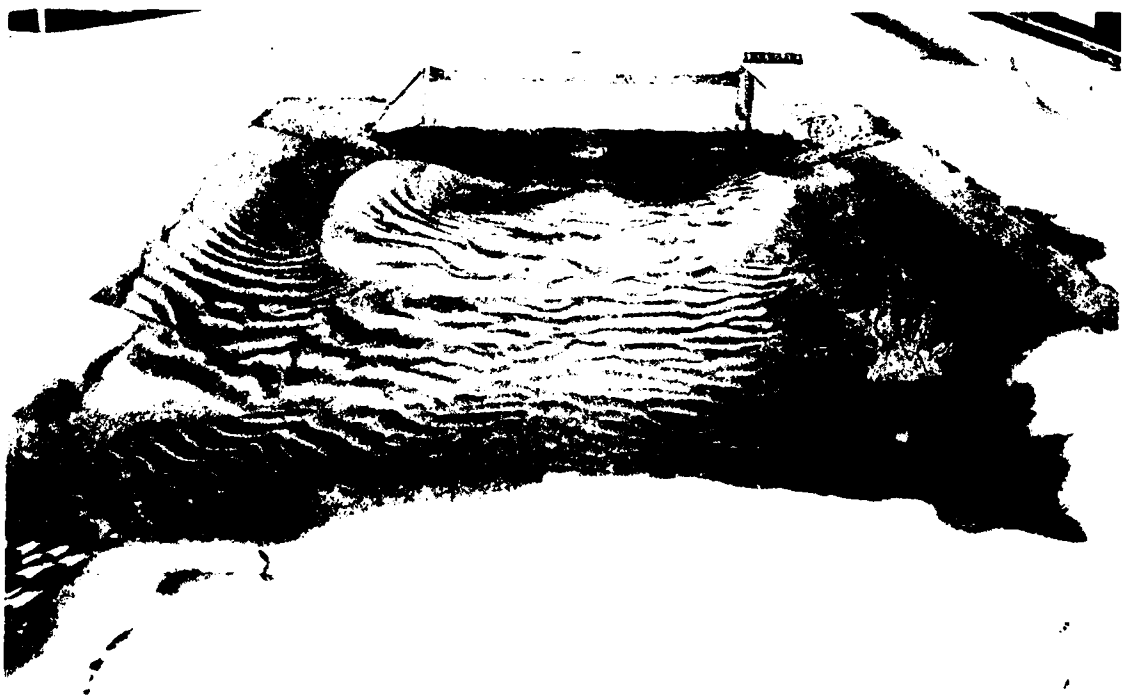
a. Existing tailwater el 234.3

b. Tailwater with ultimate degraded channel conditions, el 233.0

Photo 27. Looking upstream at flow conditions in exit channel of high-stage structure (original design); discharge 14,800 cfs



a. Looking downstream



b. Looking upstream

Photo 28. Scour in exit channel of high-stage structure with original design stilling basin

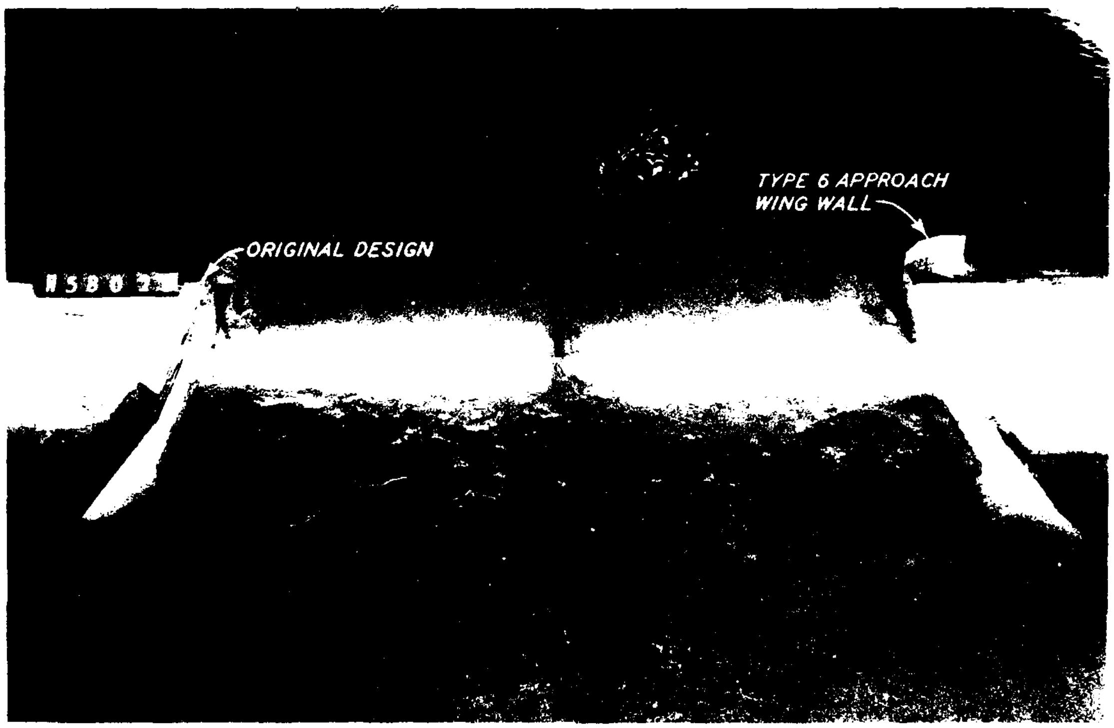
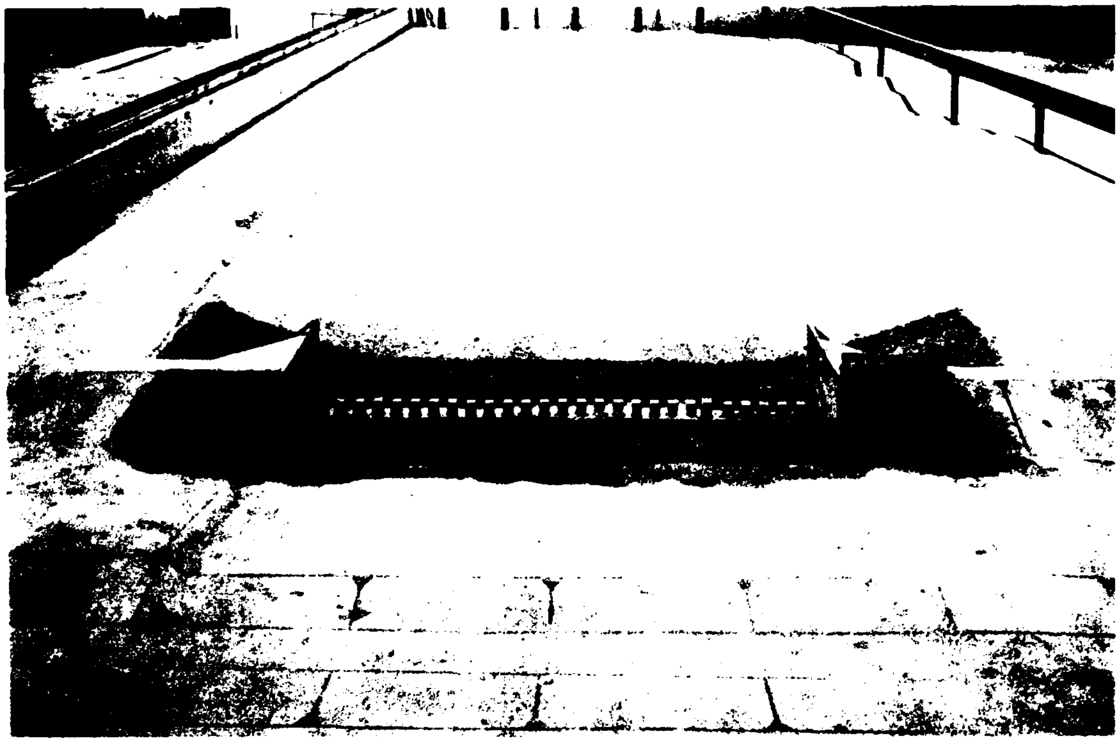


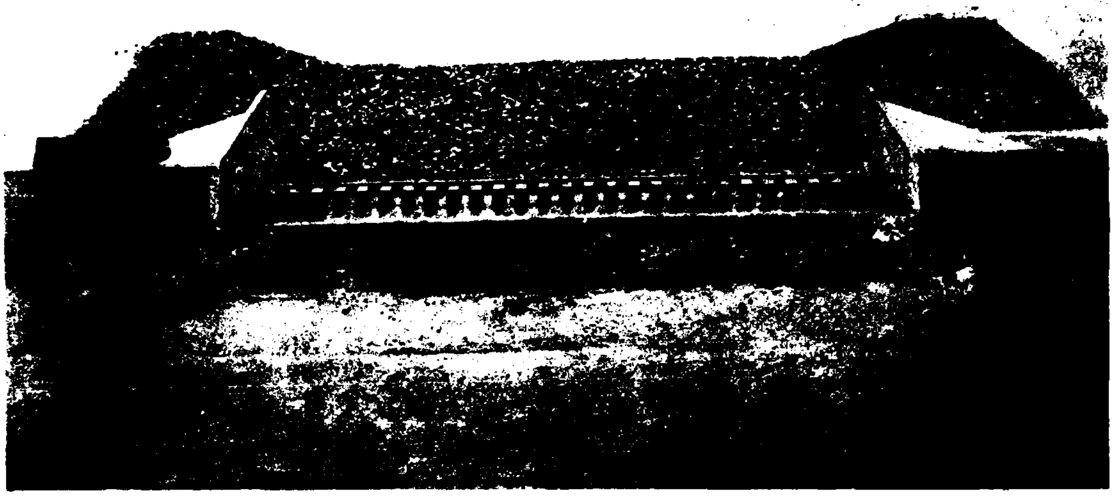
Photo 29. Looking upstream at flow conditions in exit channel of high-stage structure with type 2 design crest in stilling basin (type 6 design approach wing wall on left side looking downstream for comparison purposes); discharge 14,800 cfs, tailwater el 234.3



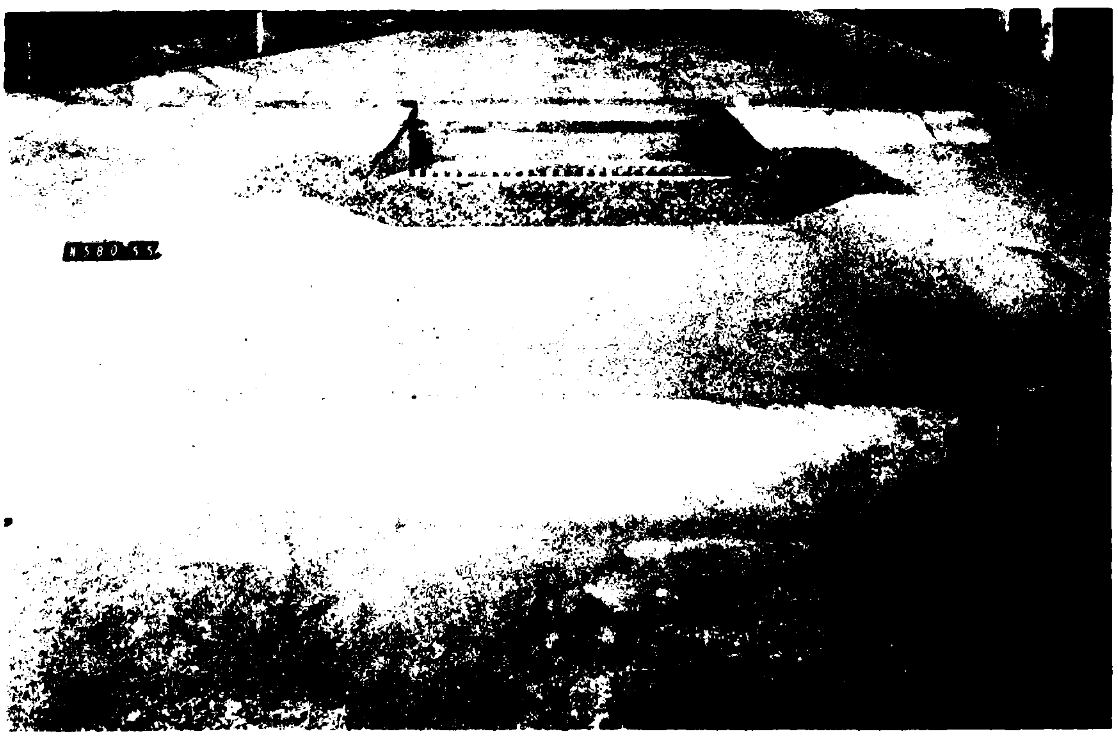
a. Looking downstream

b. Looking upstream

Photo 30. High-stage structure original riprap protection plan

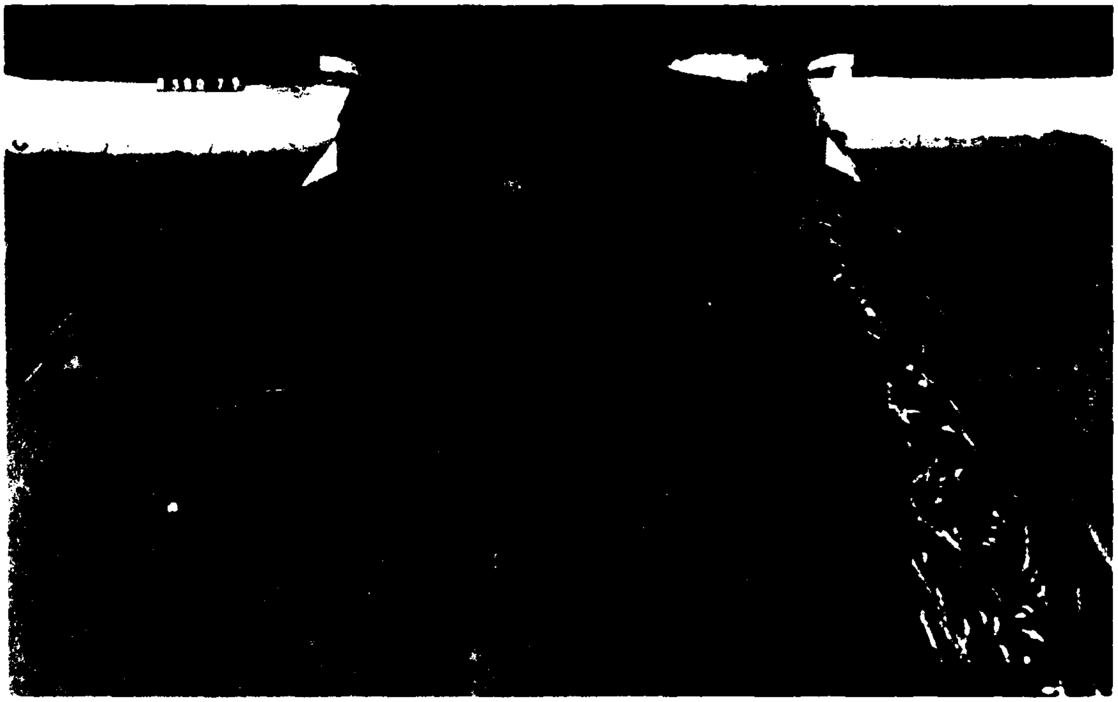


a. Looking downstream

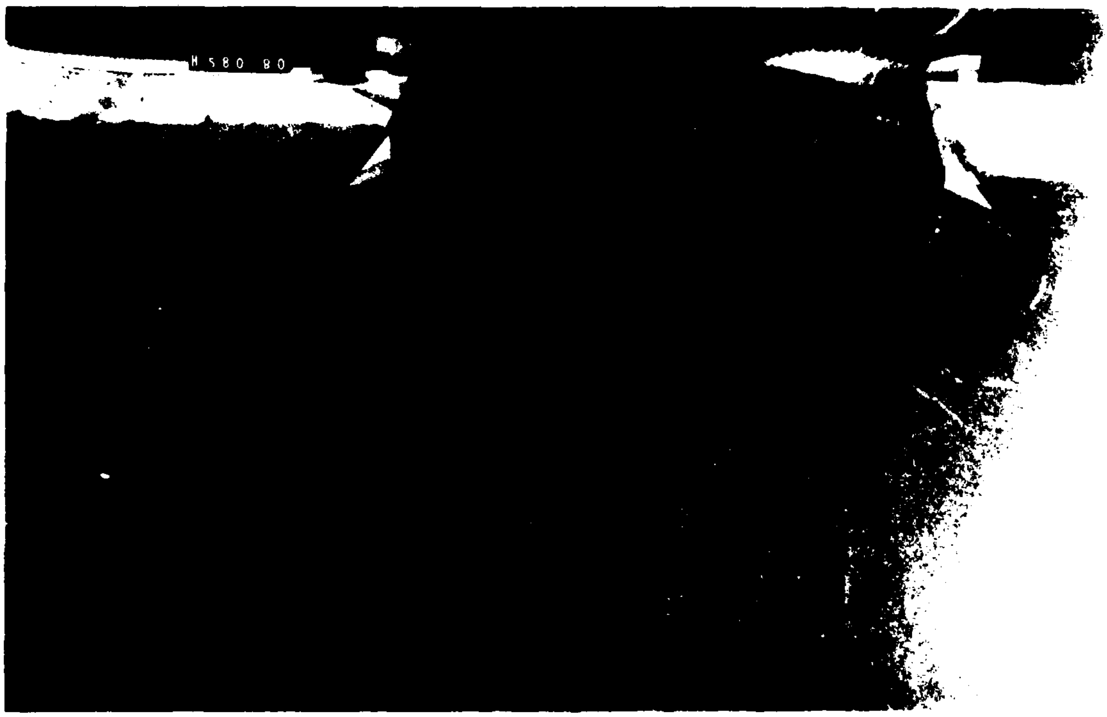


b. Looking upstream

Photo 31. High-stage structure with reduced bottom width in exit channel and type 2 design riprap plan

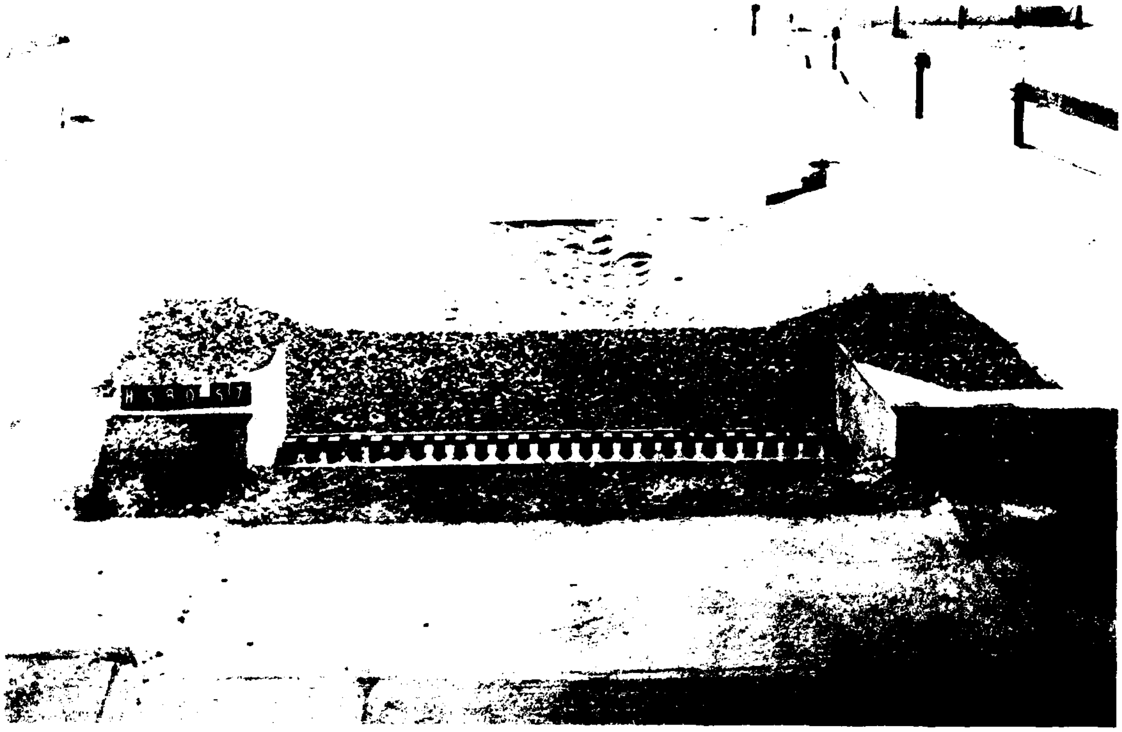


a. Existing tailwater el 234.3

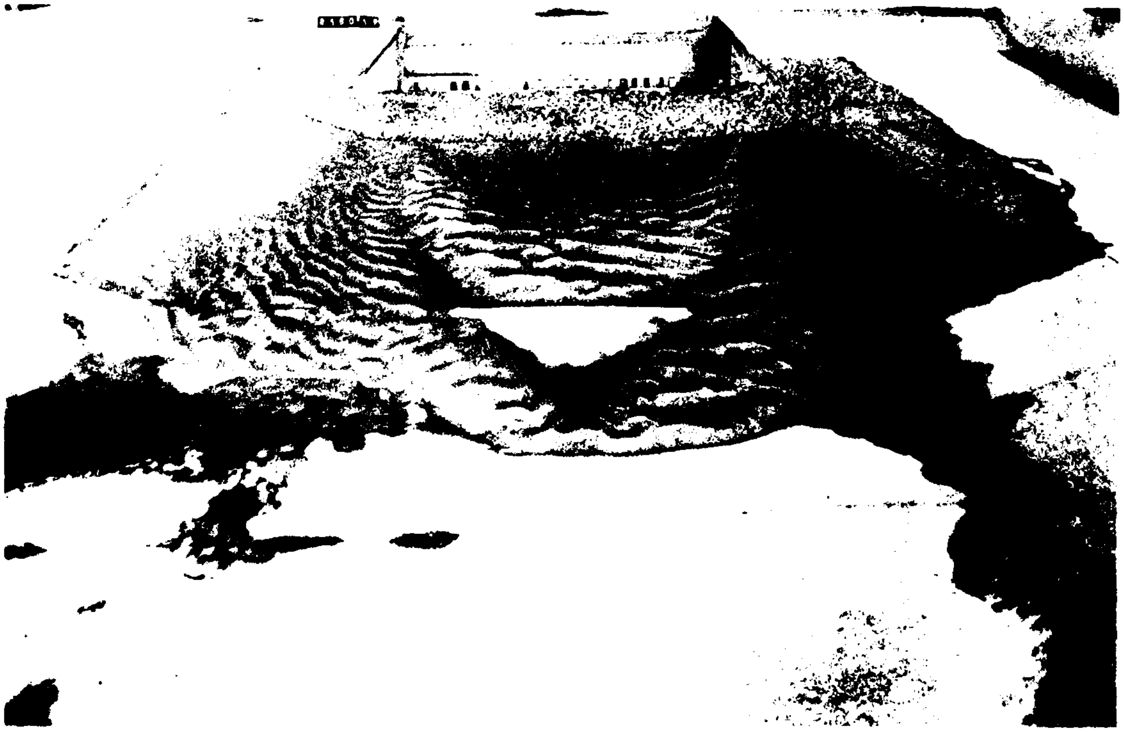


b. Tailwater el 233.0 with ultimate degraded channel conditions

Photo 32. Flow conditions with type 6 design approach wing walls, type 2 design riprap plan, and reduced bottom width in exit channel of high-stage structure for design discharge 14,800 cfs

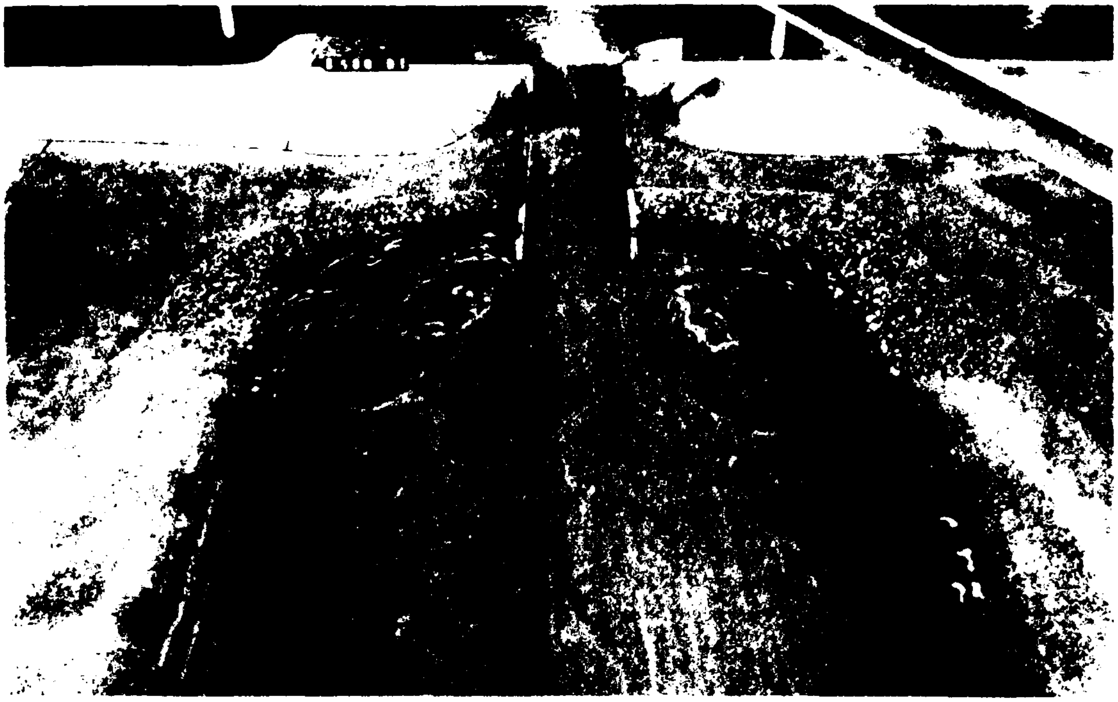


a. Looking downstream

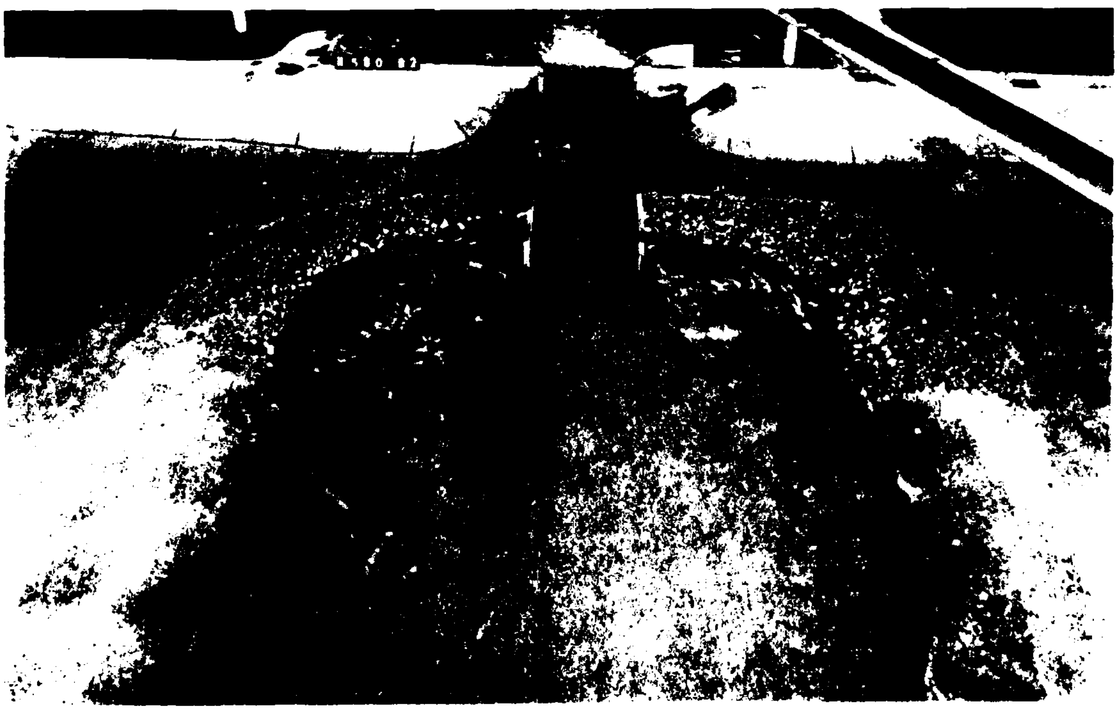


b. Looking upstream

Photo 33. Scour in exit channel of high-stage structure with reduced bottom width, type 2 design riprap plan, and type 6 design approach wing walls

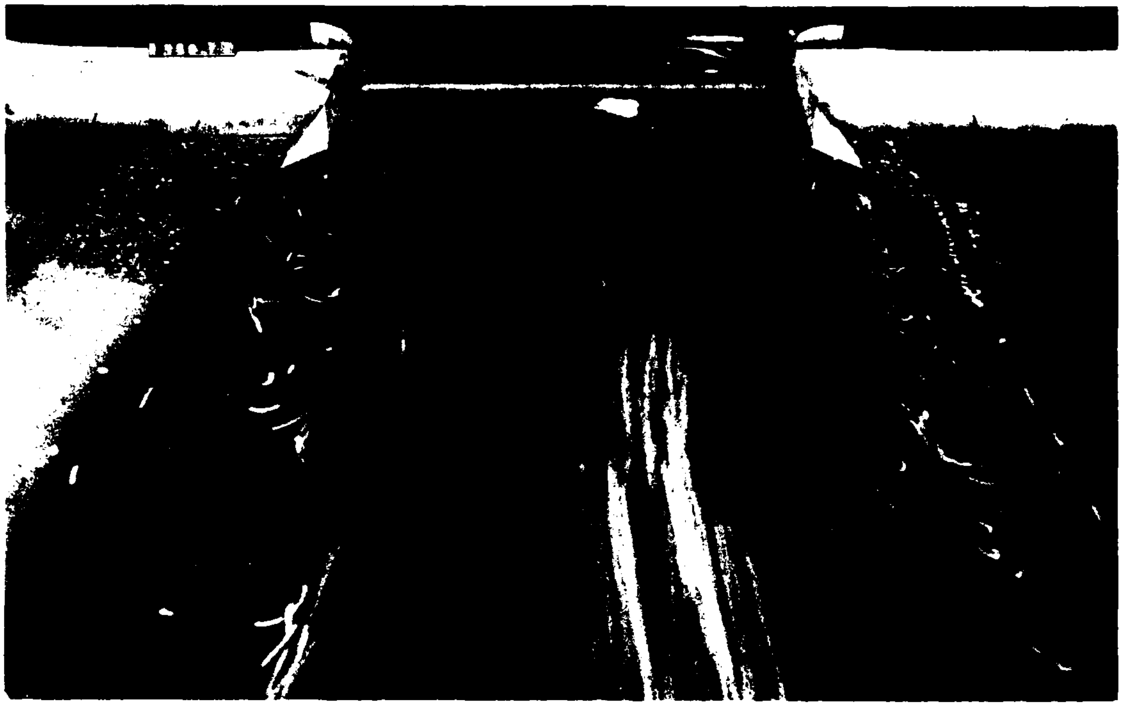


a. Existing tailwater el 230.8

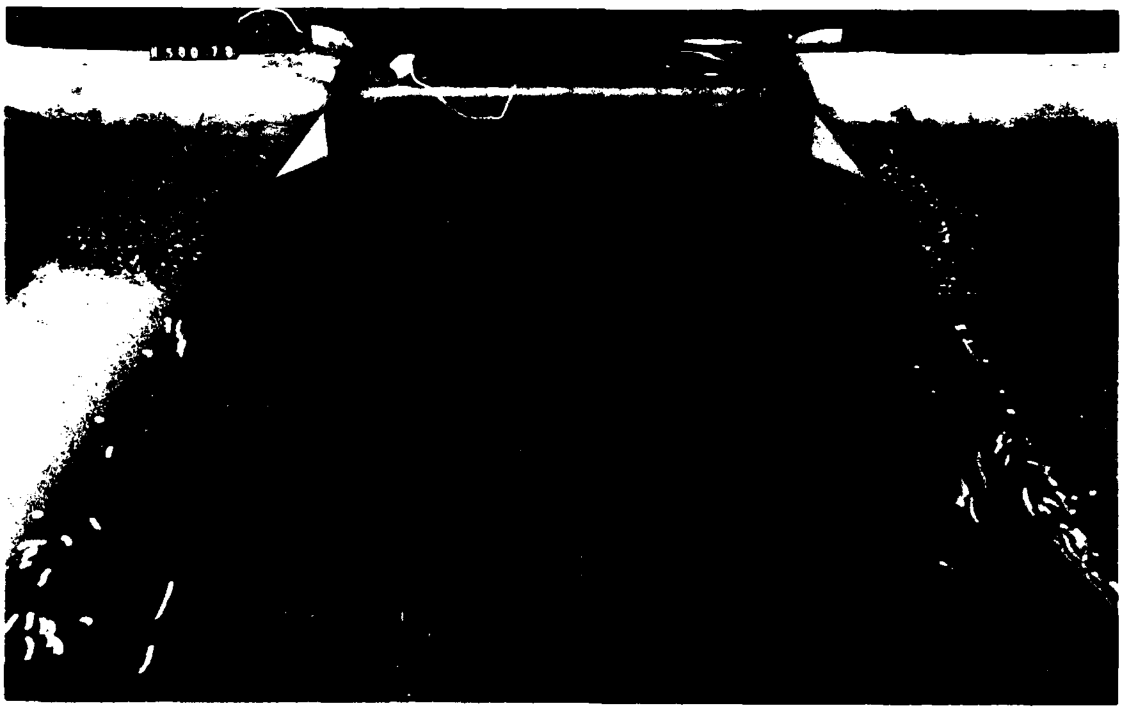


b. Tailwater el 229.2 with ultimate degraded channel conditions

Photo 34. Flow conditions with the type 7 design approach wing walls, type 4 design crest, exit wing walls removed, and reduced bottom width in exit channel of low-stage structure for peak discharge (8,800 cfs) from 50-year storm



a. Existing tailwater el 230.8



b. Tailwater el 229.2 with ultimate degraded channel conditions

Photo 35. Flow conditions with type 6 approach wing walls, type 2 design riprap plan, and reduced bottom width in exit channel of high-stage structure for peak discharge (8,800 cfs) from 50-year storm

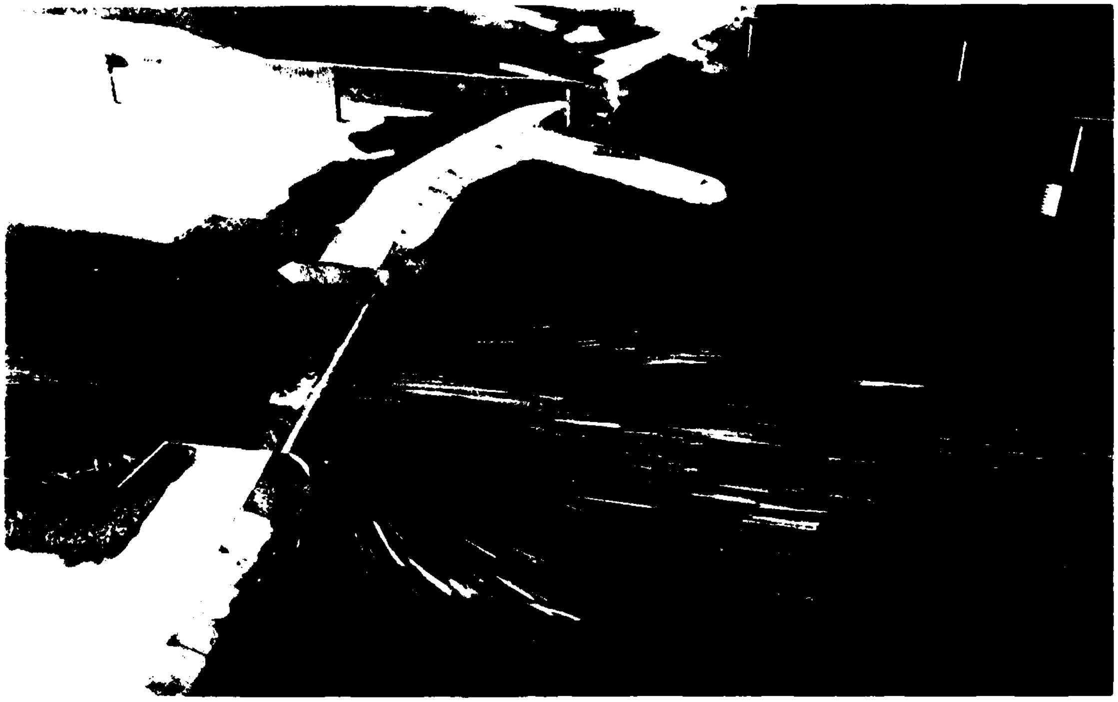
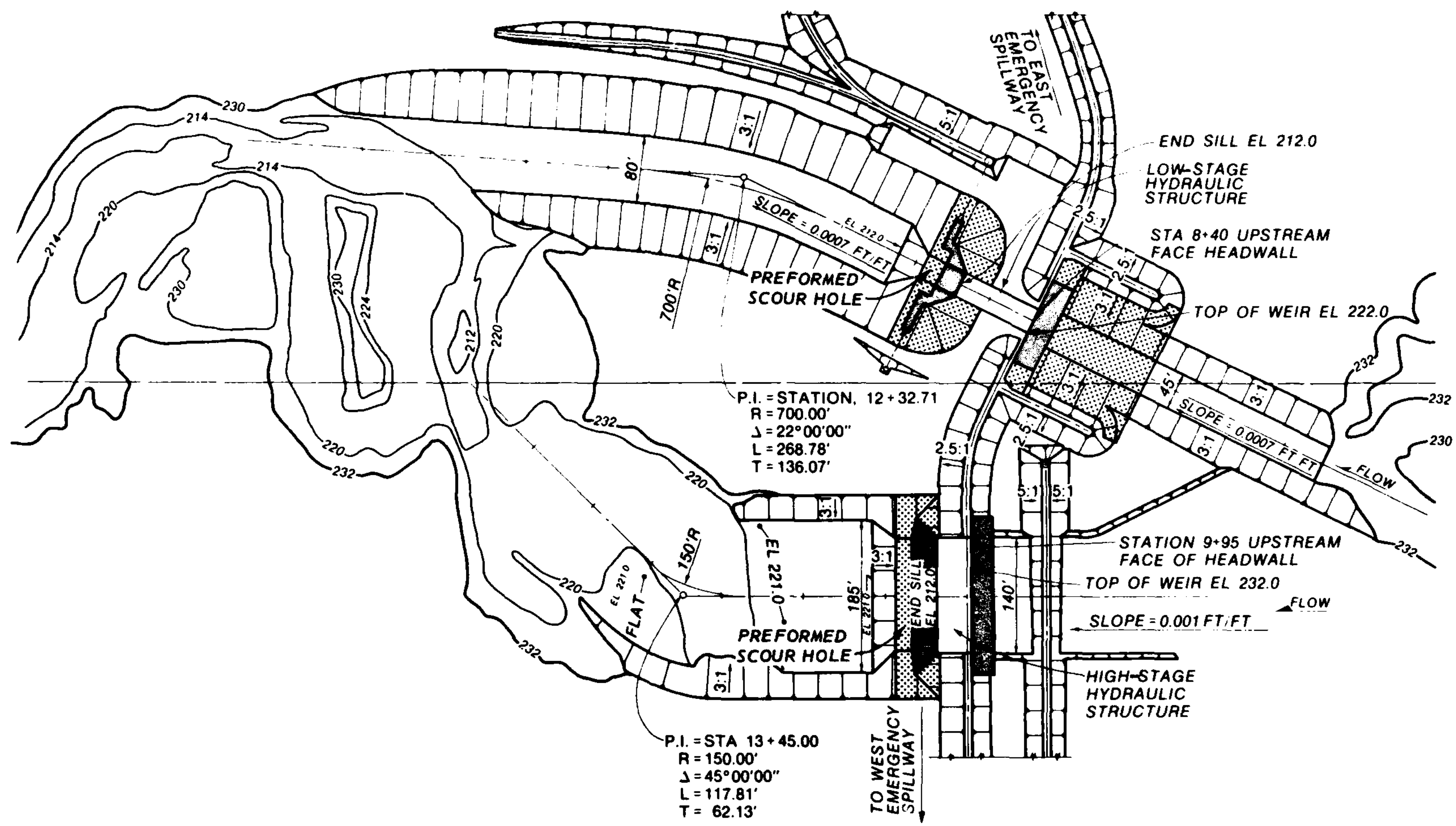


Photo 36. Flow conditions with all recommended modifications for peak discharge (8,800 cfs) from 50-year storm and existing tailwater el 230.8

Photo 37. Flow conditions with all recommended modifications for design discharge (14,800 cfs) and existing tailwater el 234.3

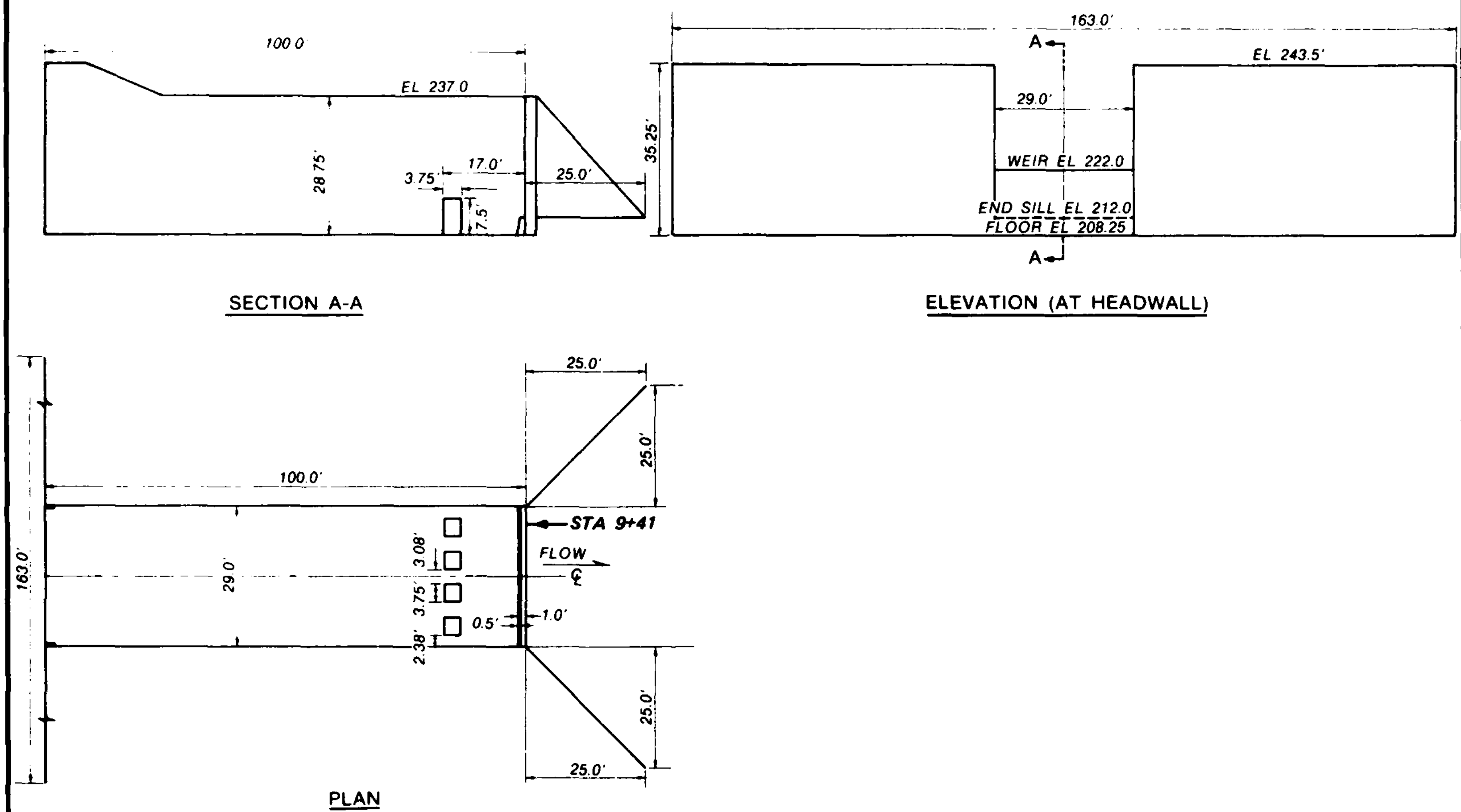


LEGEND

RIPRAP. BLANKET THICKNESS = 18 IN

GROUTED RIPRAP. BLANKET THICKNESS = 18 IN

PLAN VIEW
ORIGINAL DESIGN



LOW-STAGE STRUCTURE

PLAN, ELEVATION, AND SECTION

ORIGINAL DESIGN

PLATE 2

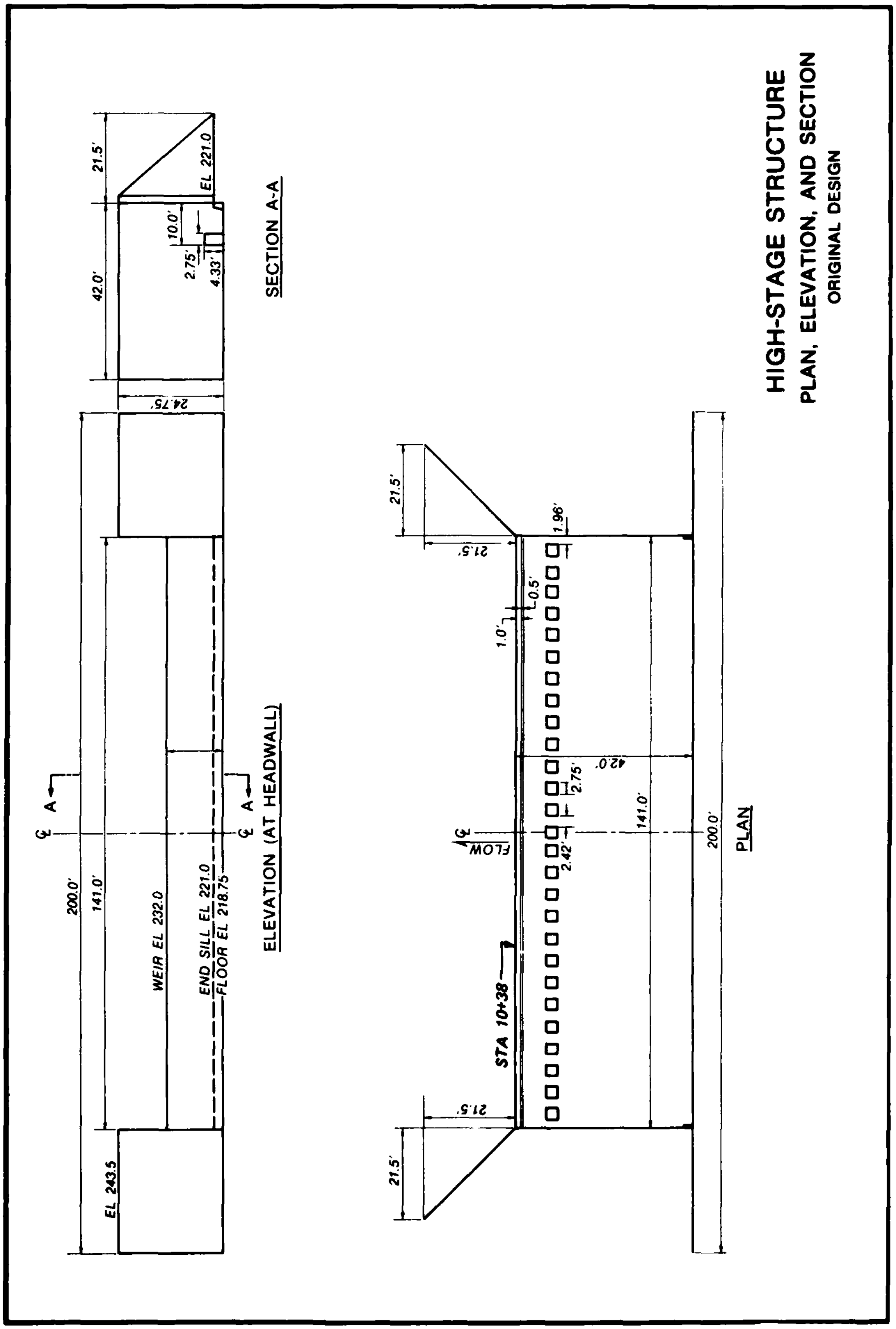
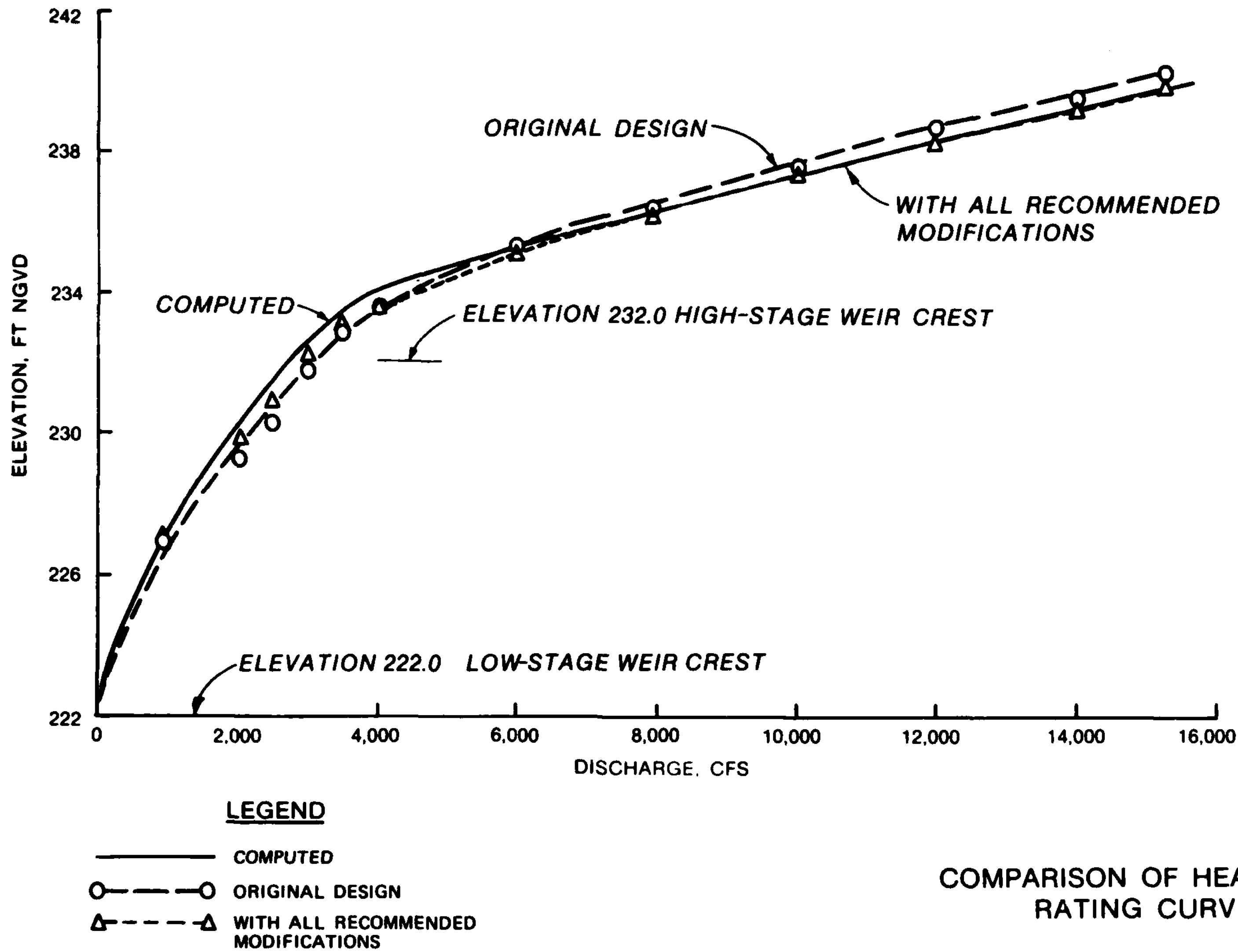
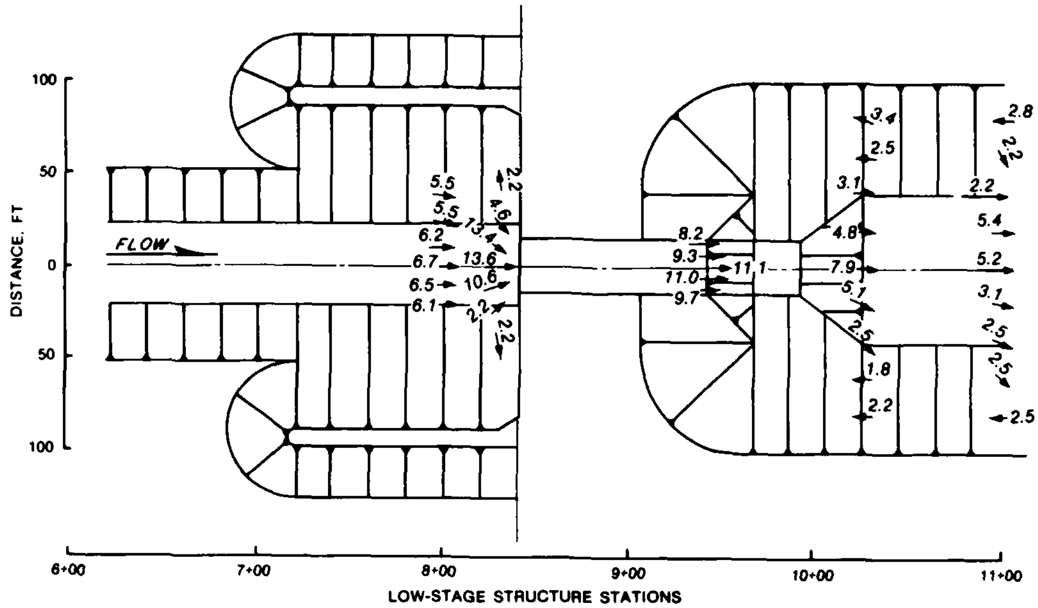

HIGH-STAGE STRUCTURE
PLAN, ELEVATION, AND SECTION
ORIGINAL DESIGN
SECTION A-A
21.5'
EL 221.0
10.0'
2.75'
4.33'
42.0'
24.75'
ELEVATION (AT HEADWALL)
200.0'
141.0'
WEIR EL 232.0
END SILL EL 221.0
FLOOR EL 218.75
EL 243.5
A
PLAN
21.5'
1.96'
0.5'
1.0'
42.0'
2.75'
2.42'
141.0'
200.0'
FLOW
STA 10+38

PLATE 3



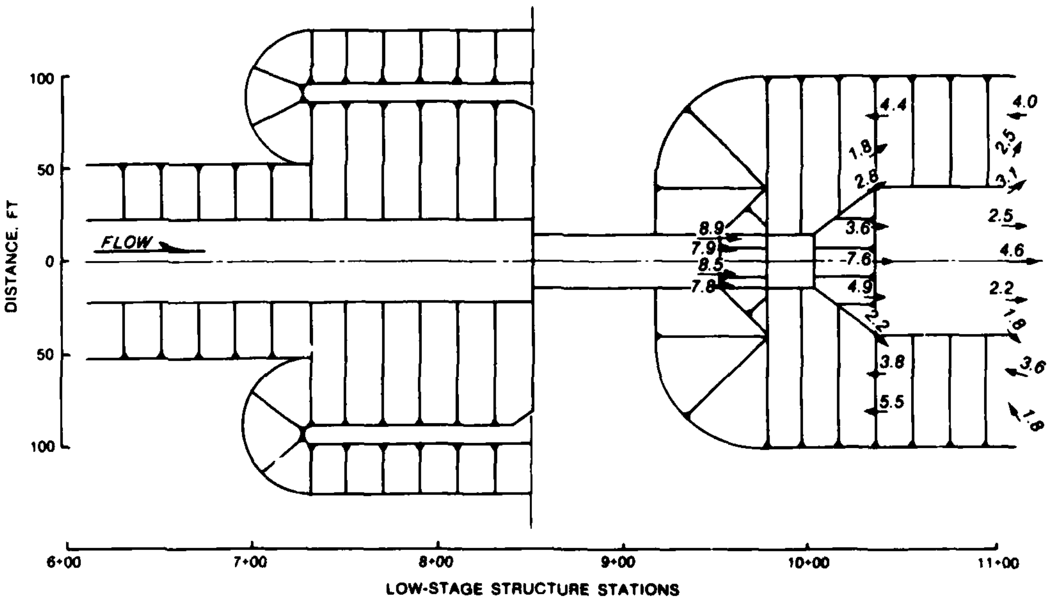
COMPARISON OF HEADWATER RATING CURVES

PLATE 4



TEST CONDITIONS

DISCHARGE 14,800 CFS
POOL EL 240.0
TAILWATER EL - 234.3

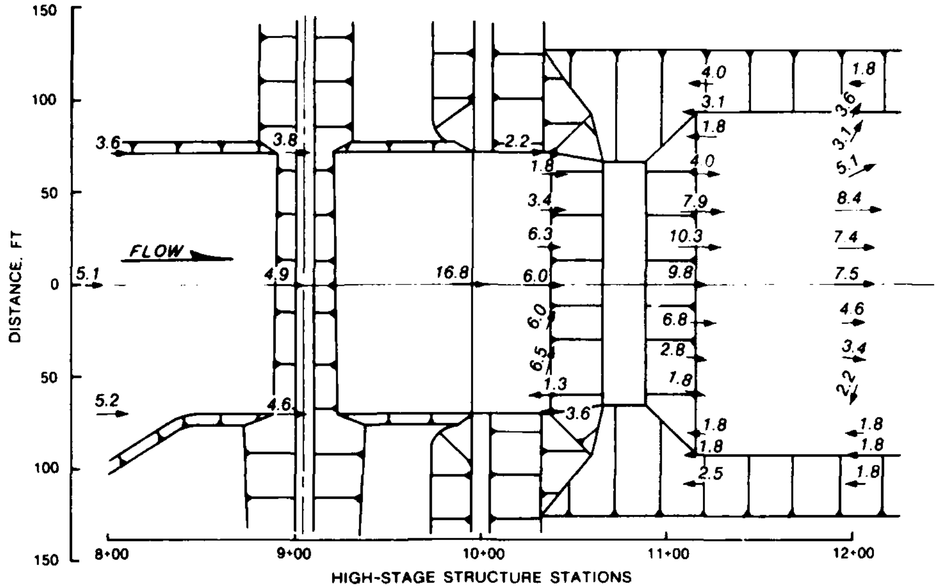


TEST CONDITIONS

DISCHARGE 14,800 CFS
POOL EL 240.0
TAILWATER EL - 233.0

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND TAKEN 1 FT OFF BOTTOM.

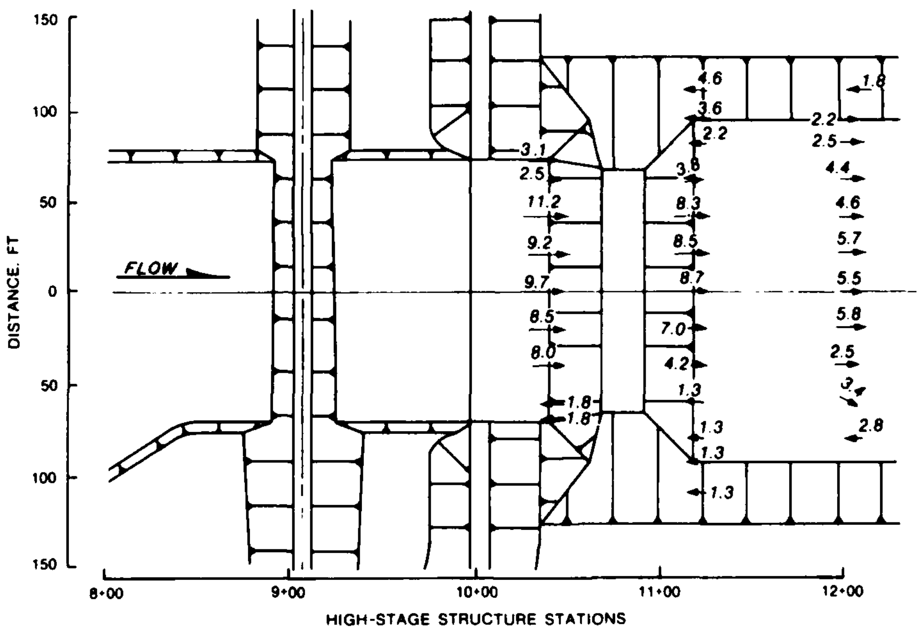
LOW-STAGE STRUCTURE
VELOCITIES
TYPE 1 (ORIGINAL) DESIGN



TEST CONDITIONS

DISCHARGE 14,800 CFS
POOL EL 240.0
TAILWATER EL 234.3

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND TAKEN 2 FT OFF BOTTOM AT STATIONS 8+00, 9+00, AND 9+95, AND 1 FT OFF BOTTOM AT STATIONS 10+38, 11+15, AND 12+00



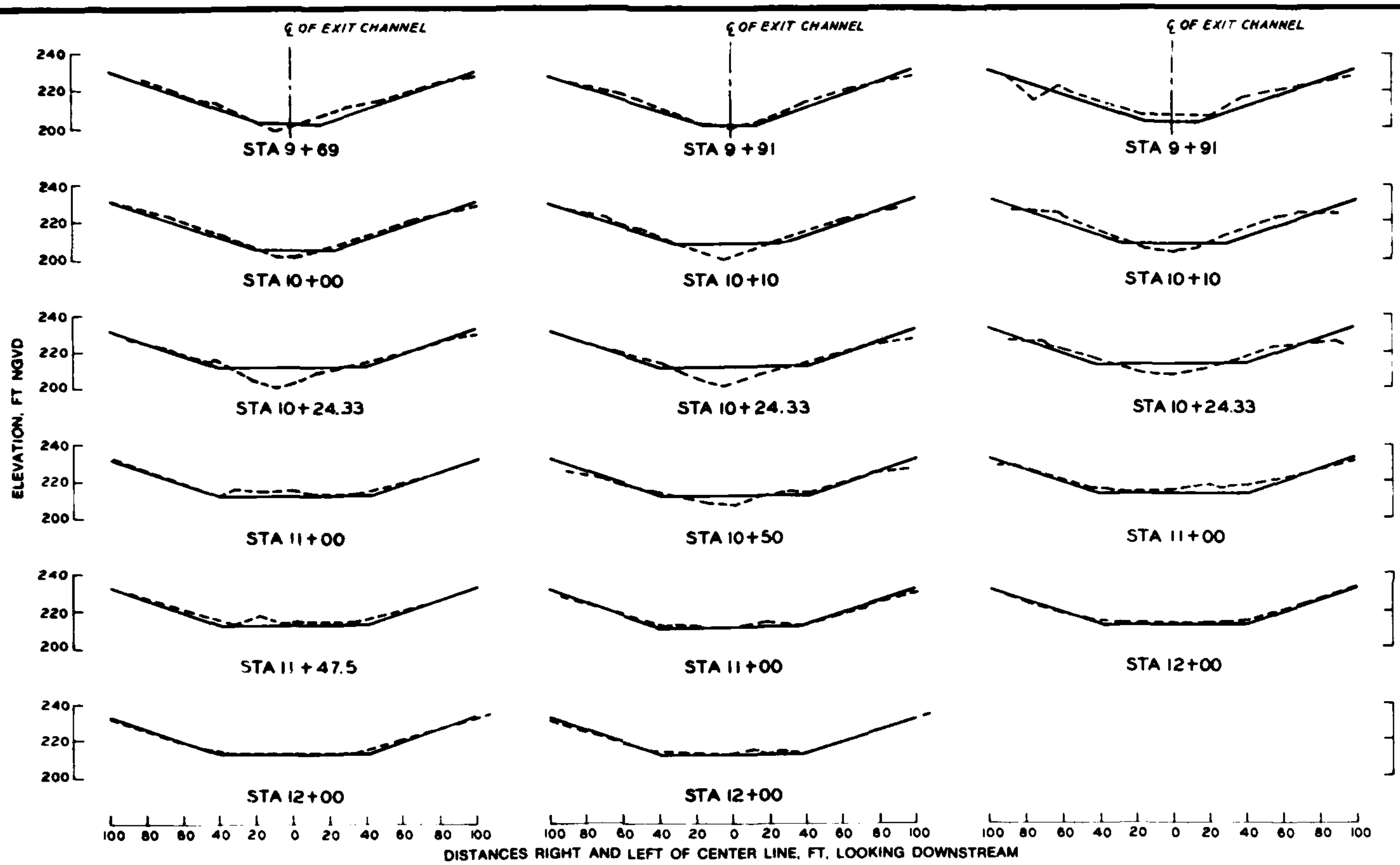
NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND TAKEN 1 FT OFF BOTTOM.

TEST CONDITIONS

DISCHARGE 14,800 CFS
POOL EL 240.0
TAILWATER EL 233.0

HIGH-STAGE STRUCTURE
VELOCITIES
TYPE 1 (ORIGINAL) DESIGN

PLATE 6



TYPE 1 WEIR (ORIGINAL DESIGN)

TYPE 3 CREST
TYPE 2 ABUTMENTS

TYPE 4 CREST
TYPE 2 ABUTMENTS

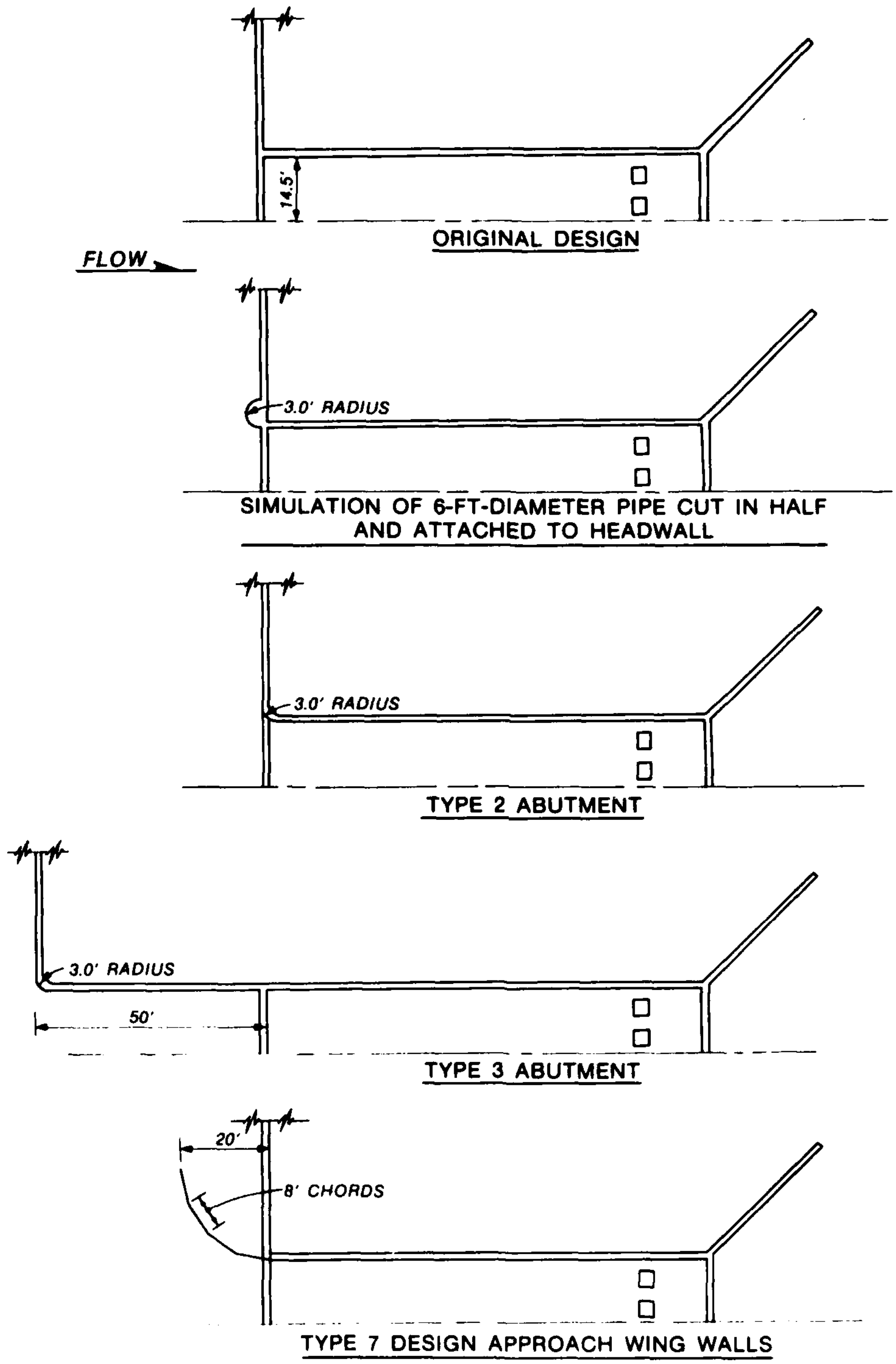
LEGEND

——— TOPOGRAPHY BEFORE HYDROGRAPH WITH PEAK DISCHARGE OF 14,800 CFS

- - - - - TOPOGRAPHY AFTER HYDROGRAPH WITH PEAK DISCHARGE OF 14,800 CFS

LOW-STAGE STRUCTURE

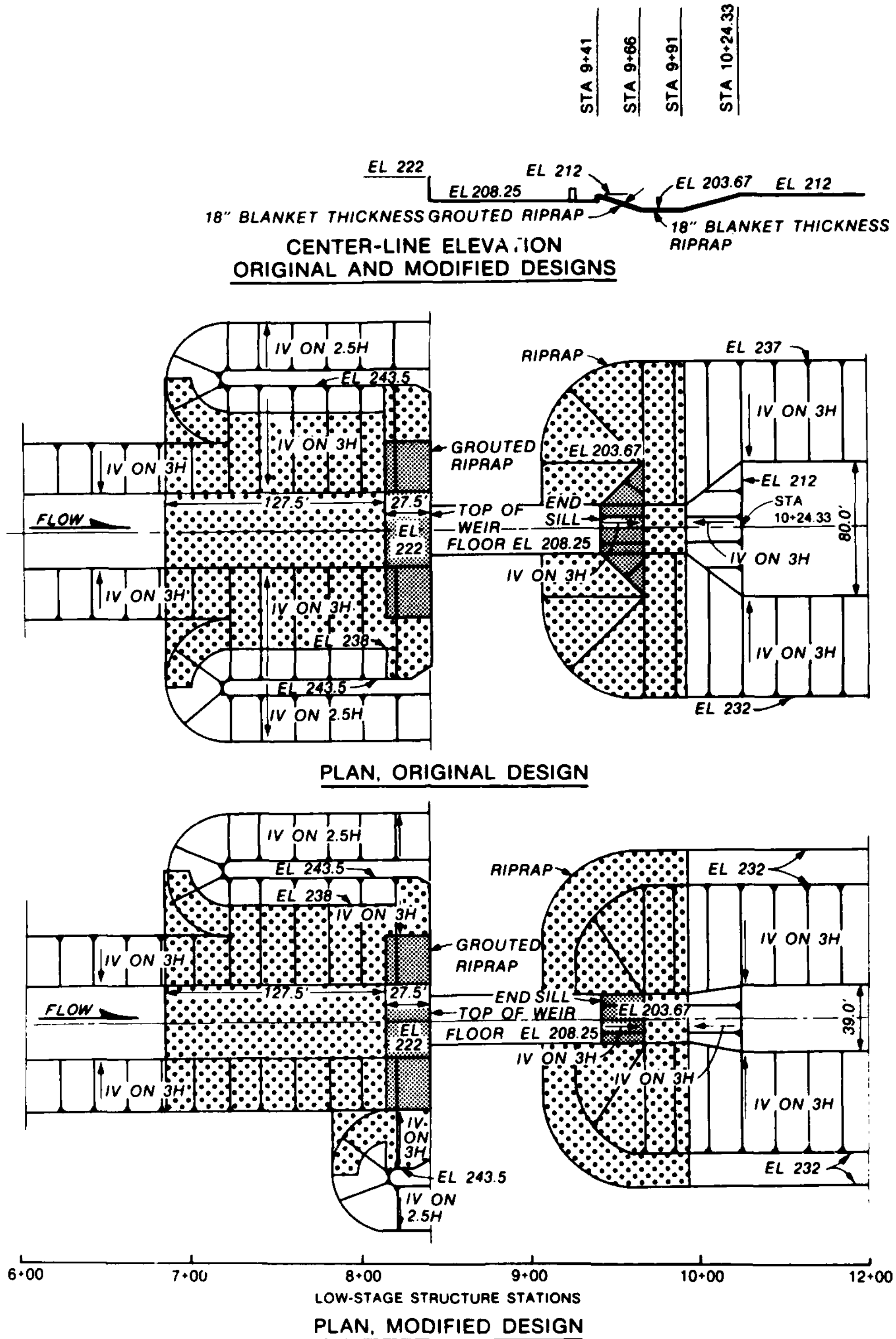
SCOUR CROSS SECTIONS
ORIGINAL EXIT CHANNEL



NOTE WING WALL HEIGHT · 21.5 FT

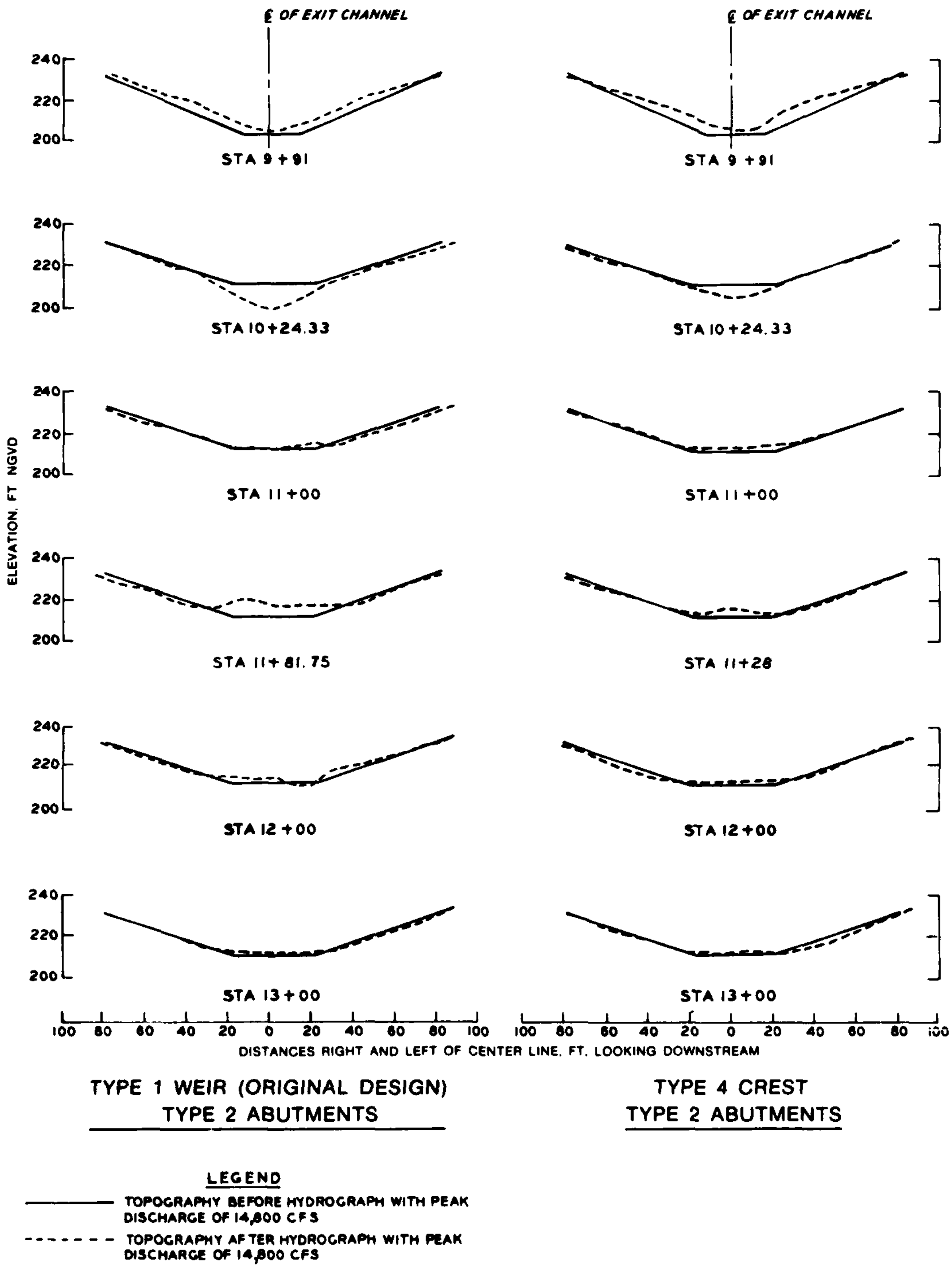
LOW-STAGE STRUCTURE
MODIFICATIONS TO ABUTMENT
HALF PLANS

PLATE 8



PLAN, MODIFIED DESIGN

LOW-STAGE STRUCTURE
MODIFICATIONS TO EXIT CHANNEL



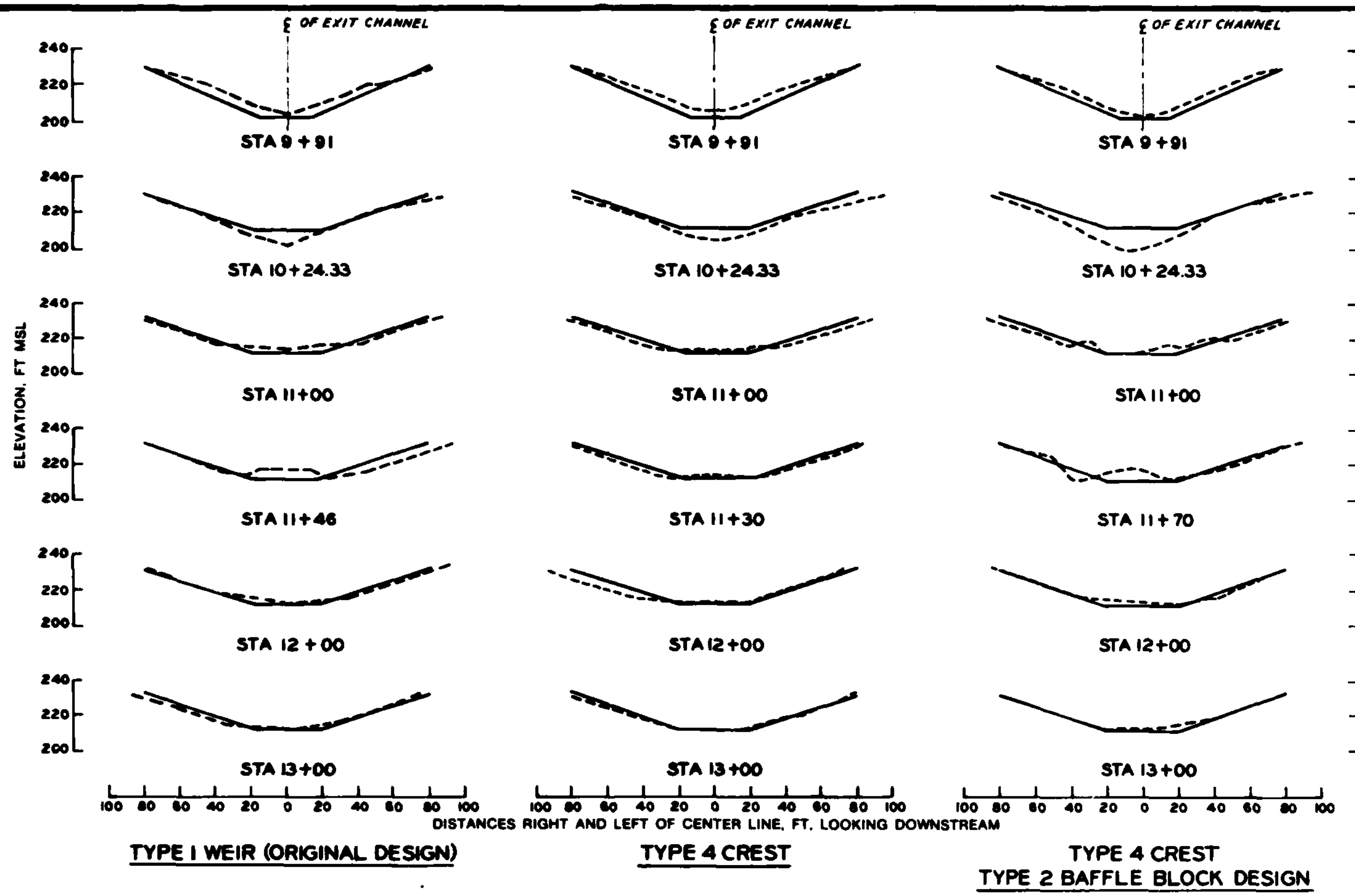
LOW-STAGE STRUCTURE

SCOUR CROSS SECTIONS

39-FT BOTTOM WIDTH

MODIFIED EXIT CHANNEL

PLATE 10



LEGEND

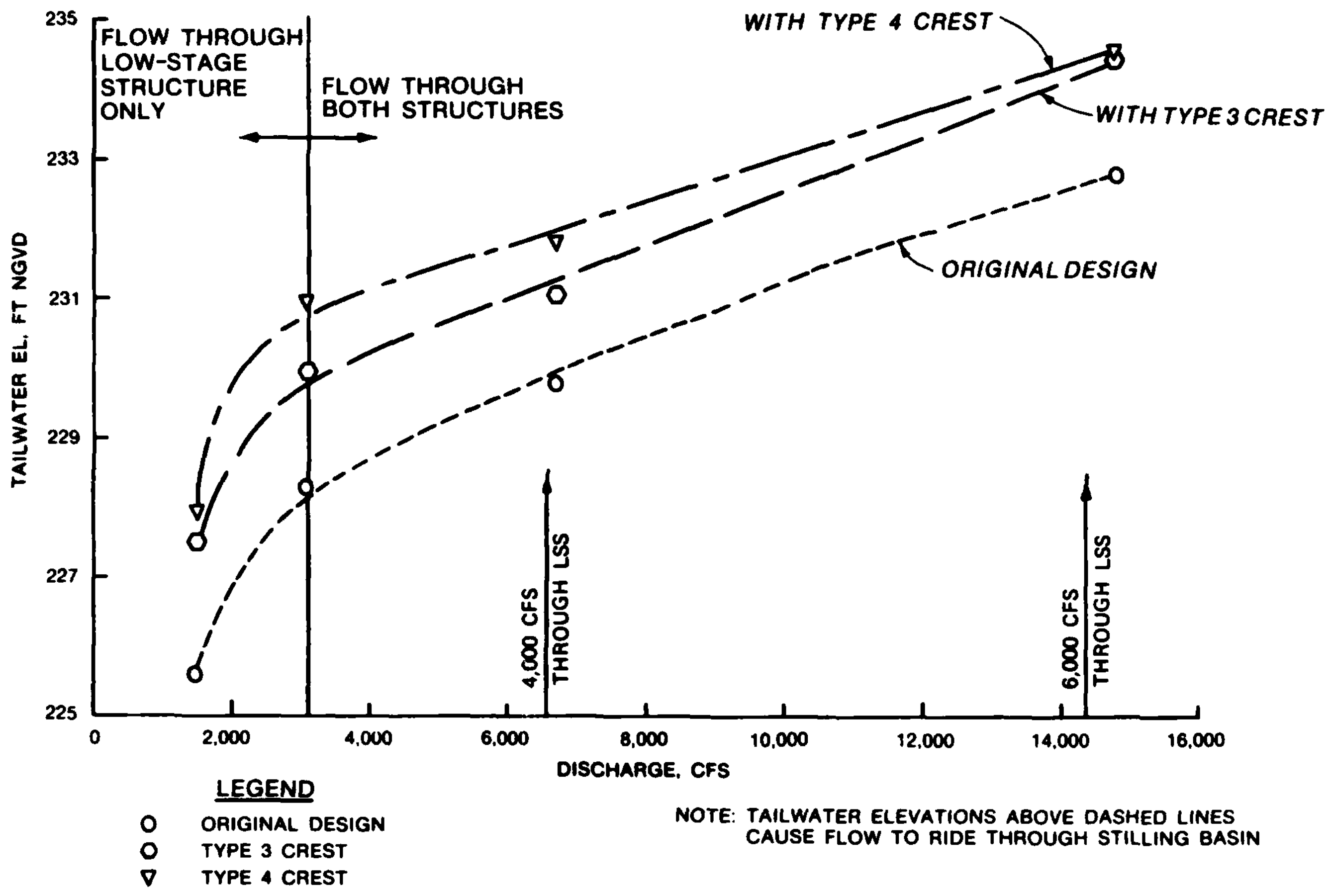
——— TOPOGRAPHY BEFORE HYDROGRAPH WITH PEAK DISCHARGE OF 14,800 CFS

- - - - - - TOPOGRAPHY AFTER HYDROGRAPH WITH PEAK DISCHARGE OF 14,800 CFS

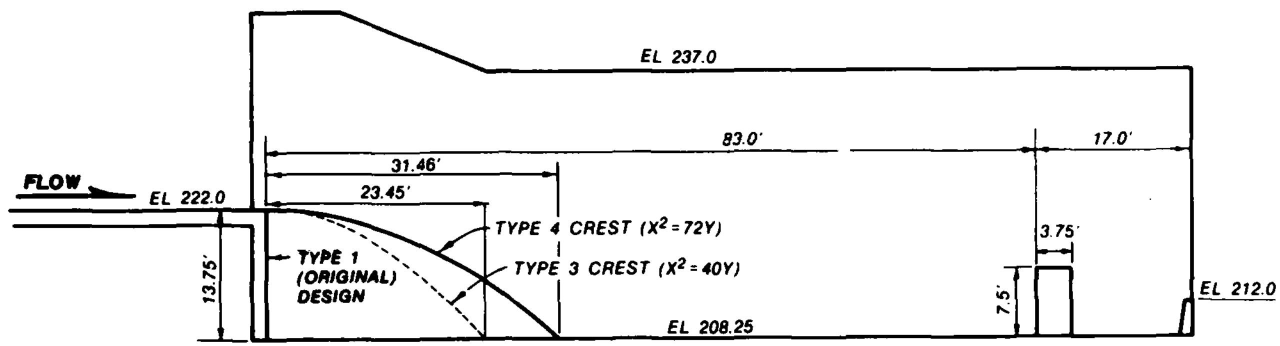
LOW-STAGE STRUCTURE WITH
TYPE 7 DESIGN APPROACH WING WALLS

SCOUR CROSS SECTIONS

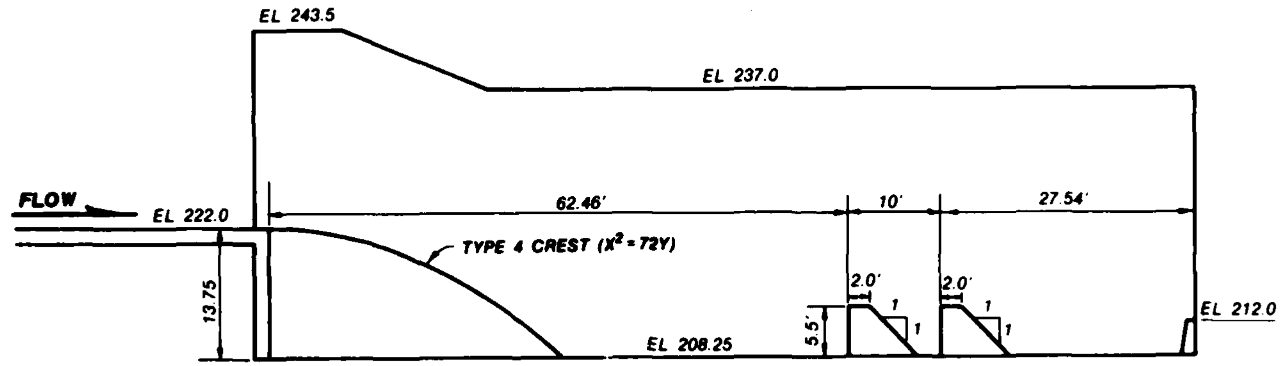
39-FT BOTTOM WIDTH IN EXIT CHANNEL



TAILWATER ELEVATION
VS DISCHARGE



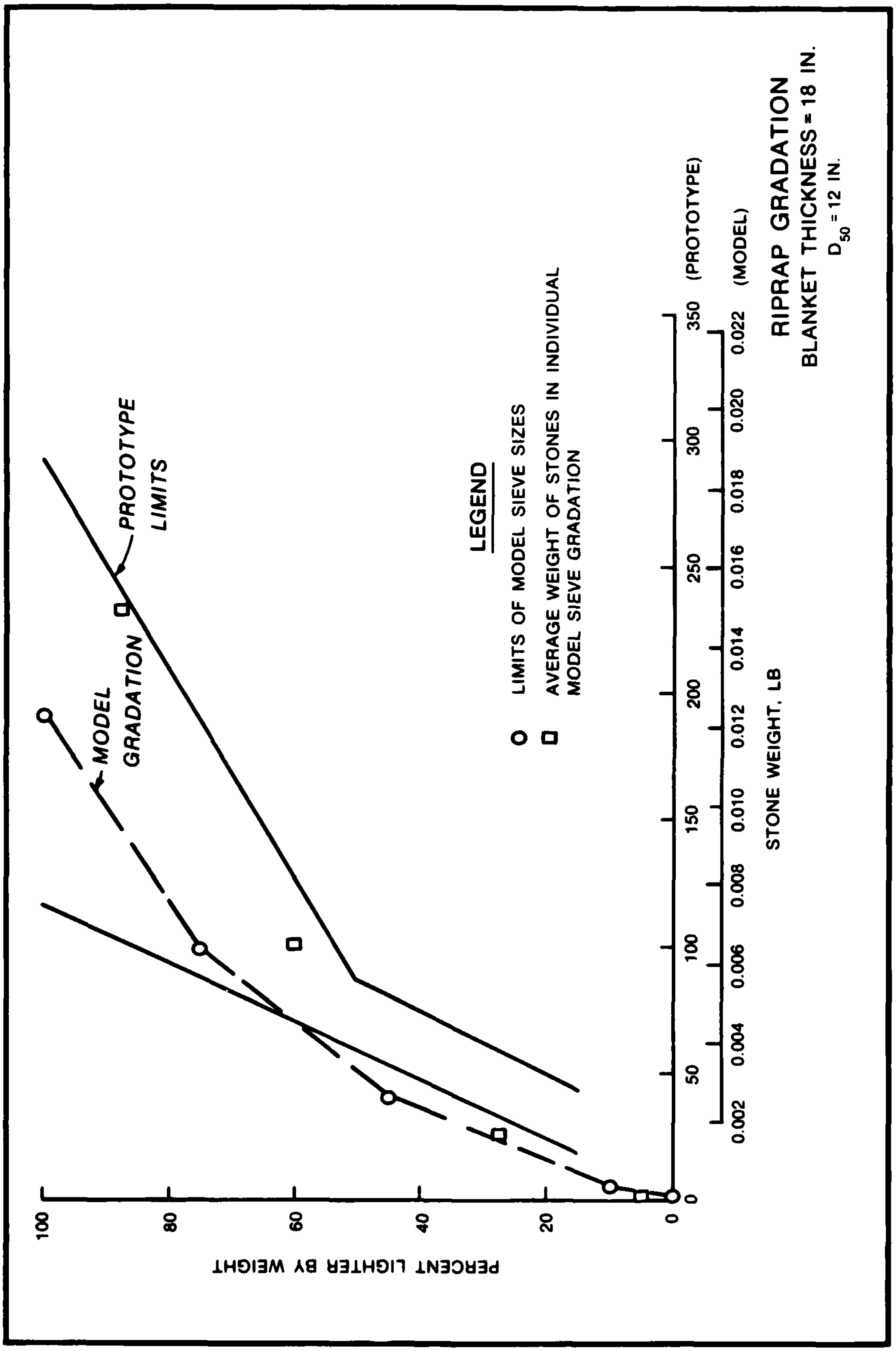
ELEVATION
TYPE 1, TYPE 3, AND TYPE 4 CREST



TYPE 2 BAFFLE BLOCK DESIGN

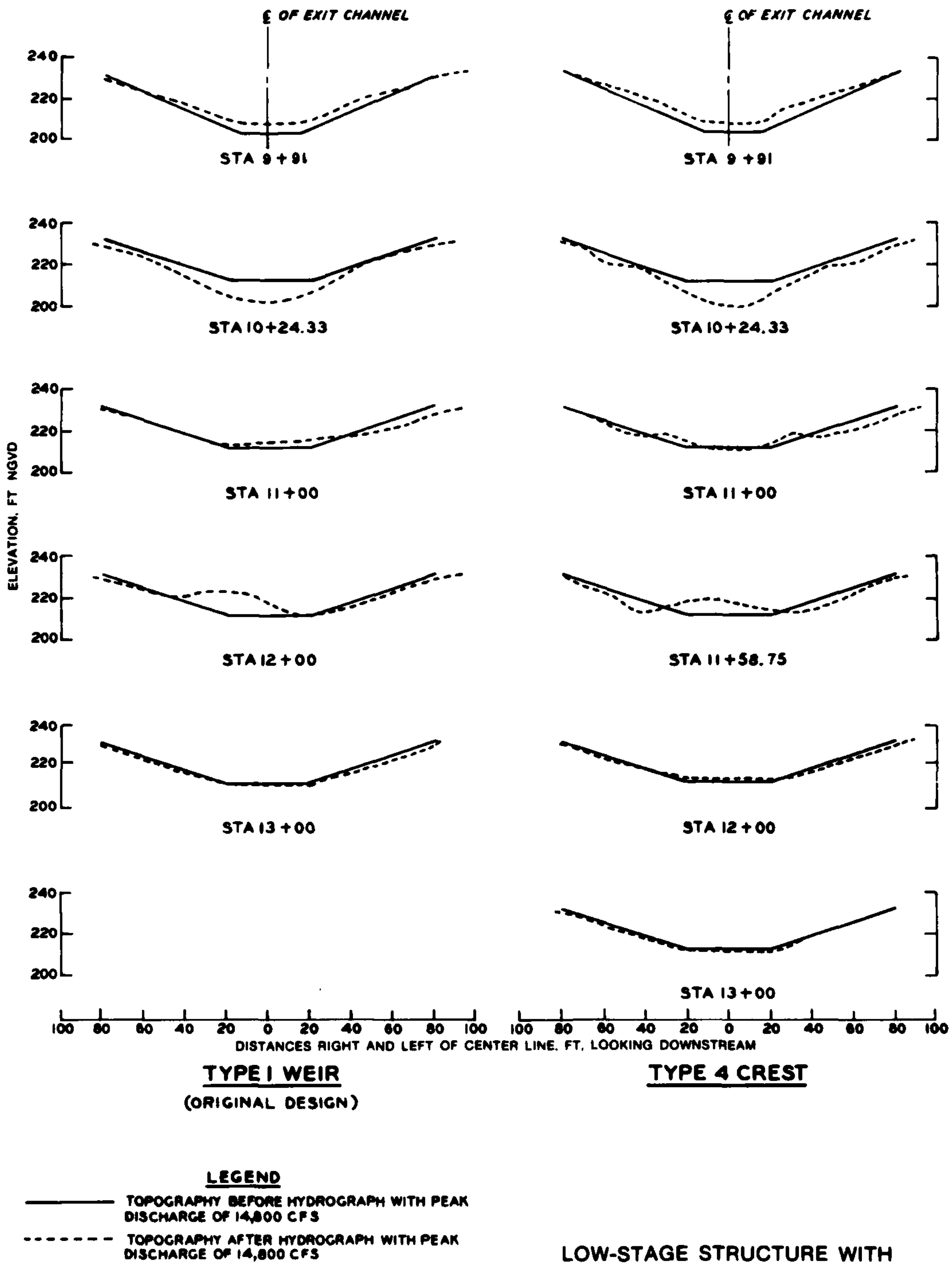
NOTE TYPE 2 BAFFLE BLOCKS ARE 3' WIDE AND SPACED 3' APART 1ST ROW CONTAINS 5 BLOCKS WITH OUTSIDE BLOCKS 1' FROM STILLING BASIN WALLS 2ND ROW CONTAINS 4 BLOCKS WITH OUTSIDE BLOCKS 4' FROM STILLING BASIN WALLS

LOW-STAGE STRUCTURE
MODIFICATIONS TO STILLING BASIN



RIPRAP GRADATION
BLANKET THICKNESS = 18 IN.
D_{50} = 12 IN.

PLATE 14



LOW-STAGE STRUCTURE WITH
TYPE 3 ENTRANCE WALLS

SCOUR CROSS SECTIONS

39-FT BOTTOM WIDTH
MODIFIED EXIT CHANNEL

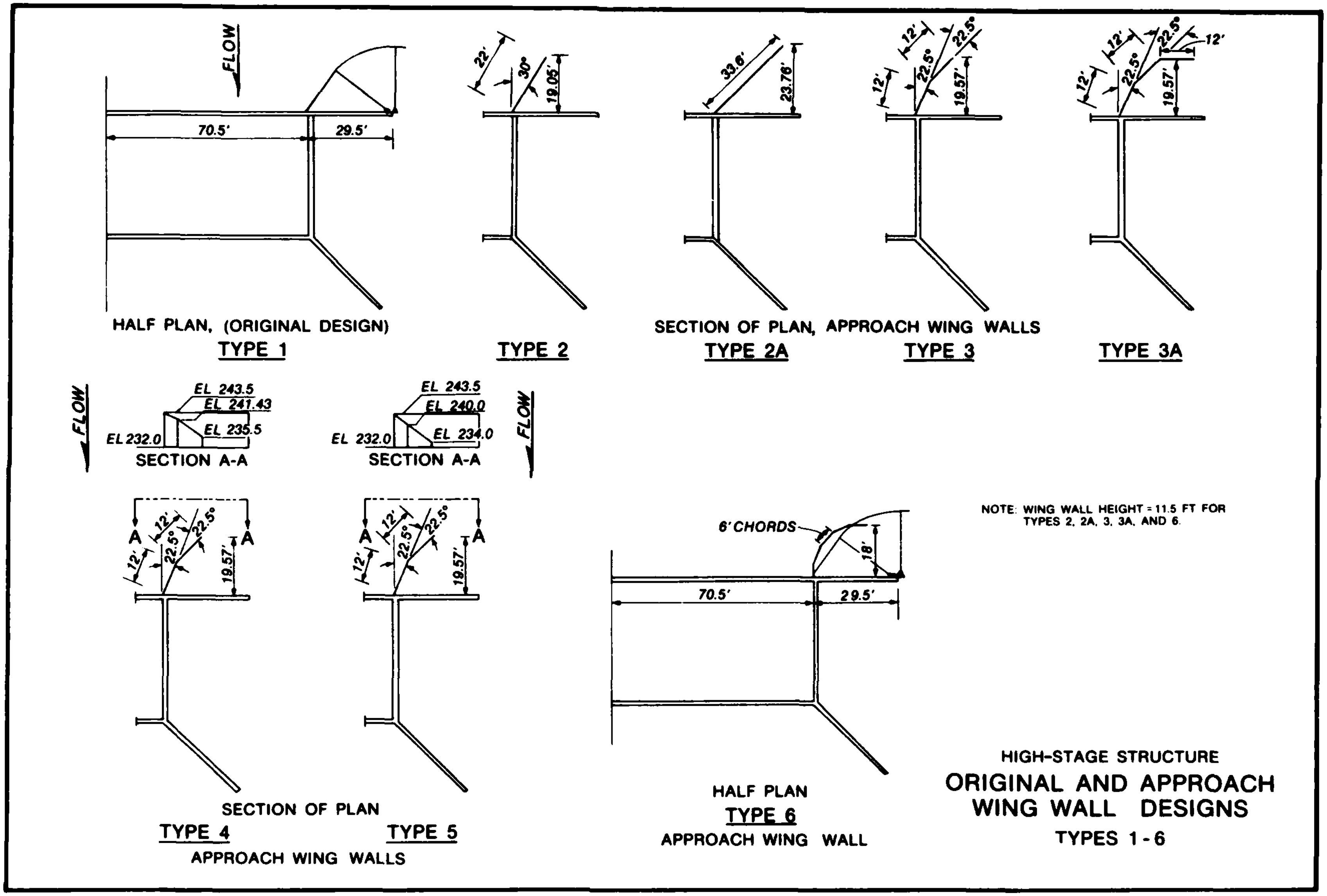
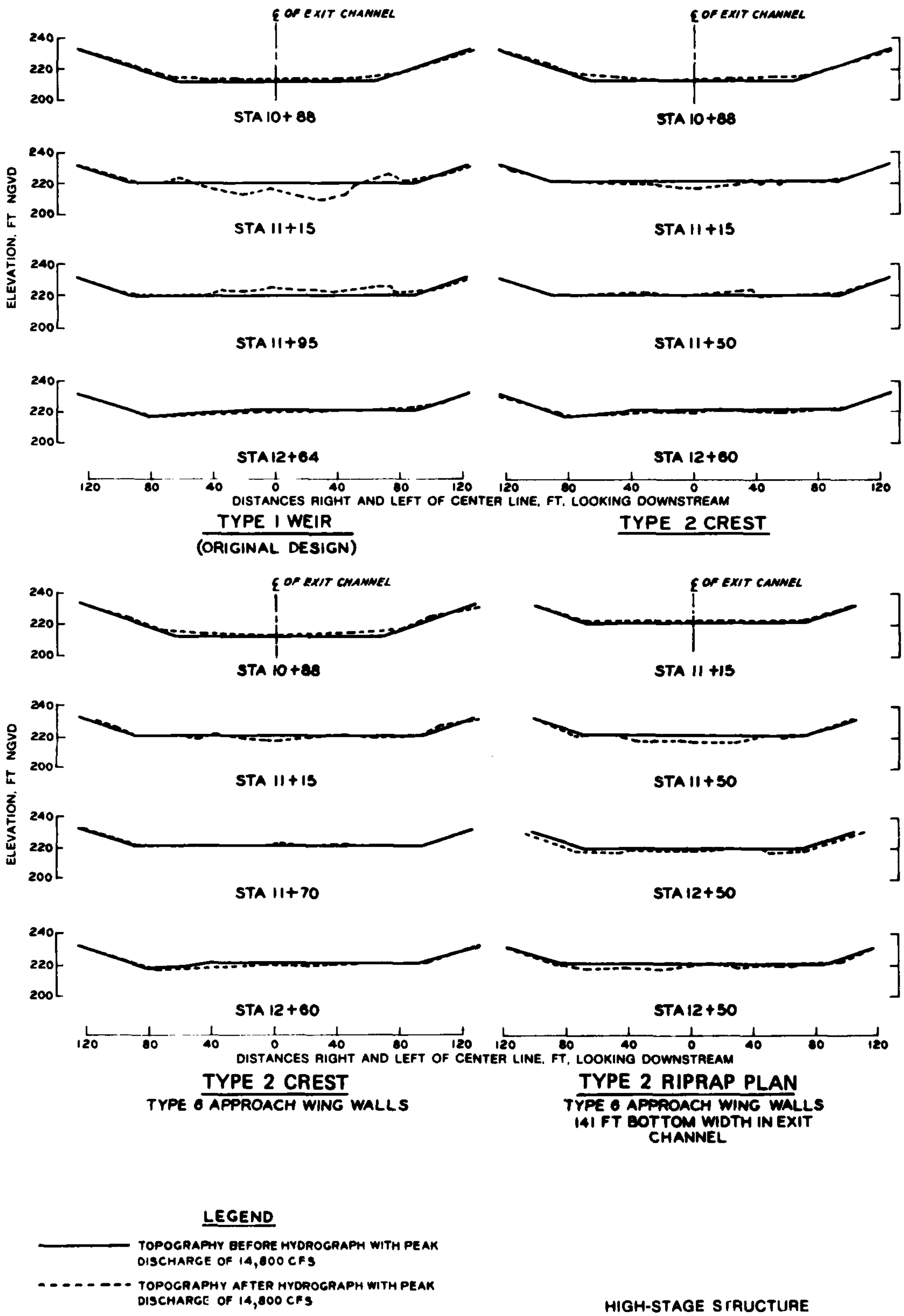
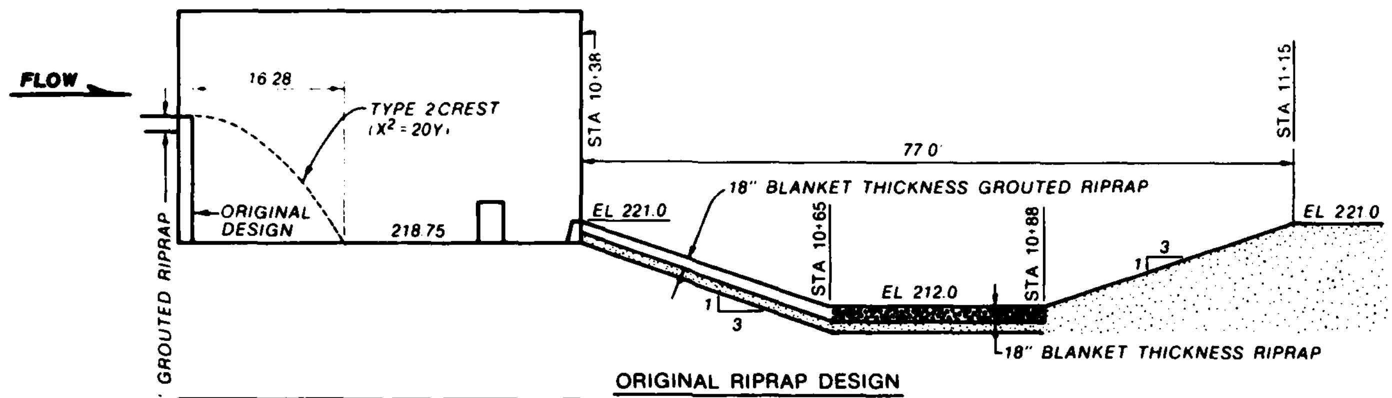

FLOW
70.5'
29.5'
HALF PLAN, (ORIGINAL DESIGN)
TYPE 1
22'
30°
19.05'
TYPE 2
33.6'
23.76'
SECTION OF PLAN, APPROACH WING WALLS
TYPE 2A
12'
12'
22.5°
22.5°
19.57'
TYPE 3
12'
12'
22.5°
22.5°
12'
19.57'
TYPE 3A
FLOW
EL 243.5
EL 241.43
EL 235.5
EL 232.0
SECTION A-A
EL 243.5
EL 240.0
EL 234.0
EL 232.0
SECTION A-A
FLOW
A
A
12'
12'
22.5°
22.5°
19.57'
A
A
12'
12'
22.5°
22.5°
19.57'
SECTION OF PLAN
TYPE 4
TYPE 5
APPROACH WING WALLS
6' CHORDS
18'
70.5'
29.5'
HALF PLAN
TYPE 6
APPROACH WING WALL
NOTE: WING WALL HEIGHT = 11.5 FT FOR
TYPES 2, 2A, 3, 3A, AND 6.
HIGH-STAGE STRUCTURE
ORIGINAL AND APPROACH
WING WALL DESIGNS
TYPES 1-6

PLATE 16

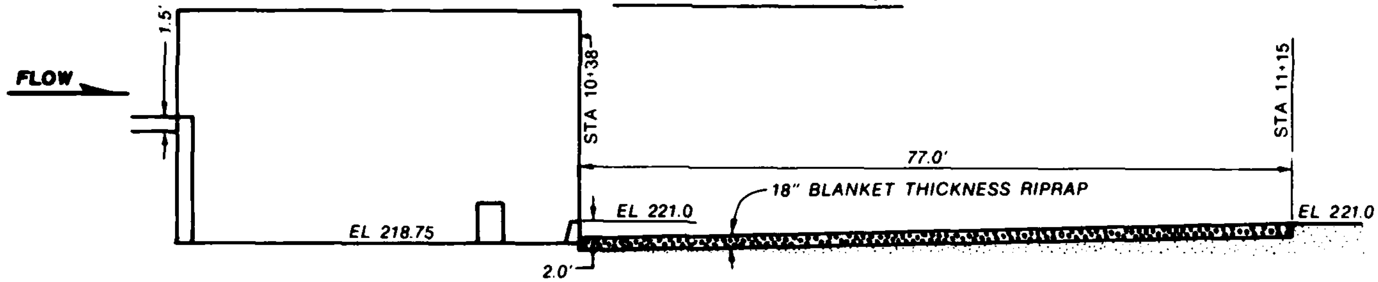


HIGH-STAGE STRUCTURE

SCOUR CROSS SECTIONS



ORIGINAL RIPRAP DESIGN

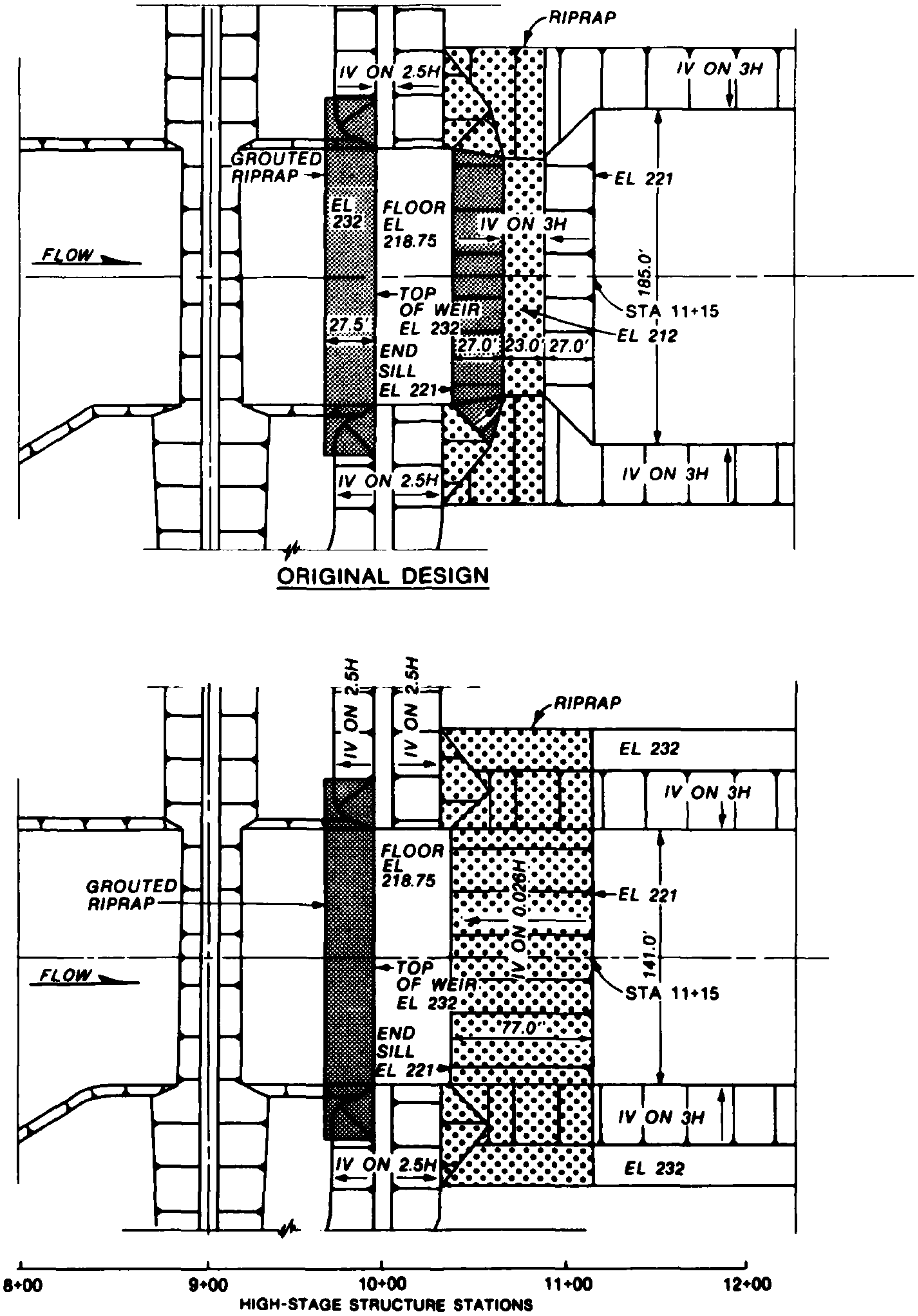


TYPE 2 RIPRAP DESIGN

HIGH-STAGE STRUCTURE

MODIFICATIONS TO STILLING BASIN AND RIPRAP PLAN

PLATE 18



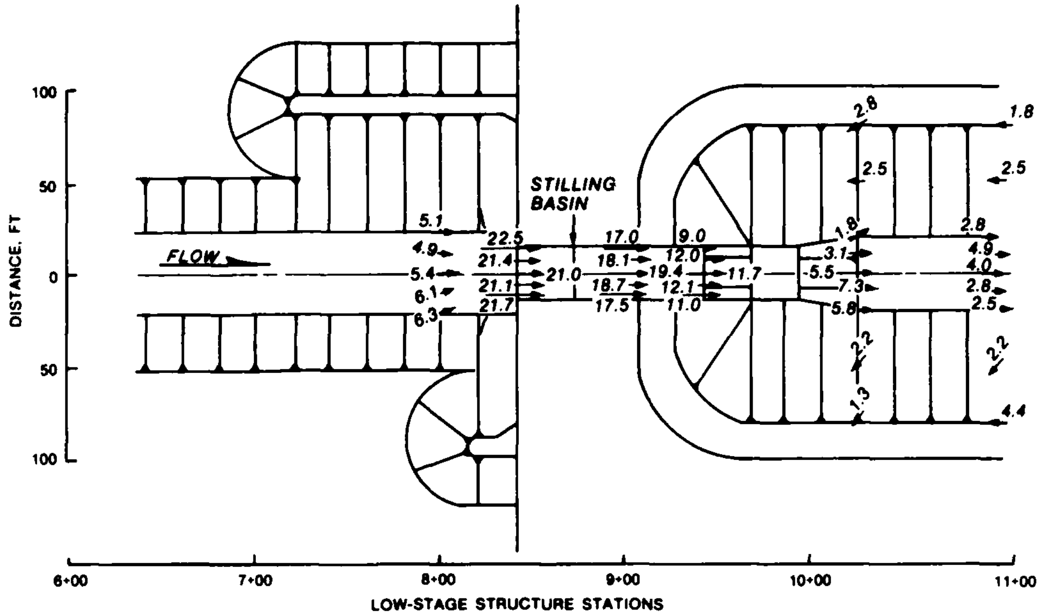
ORIGINAL DESIGN

MODIFIED DESIGN

HIGH-STAGE STRUCTURE

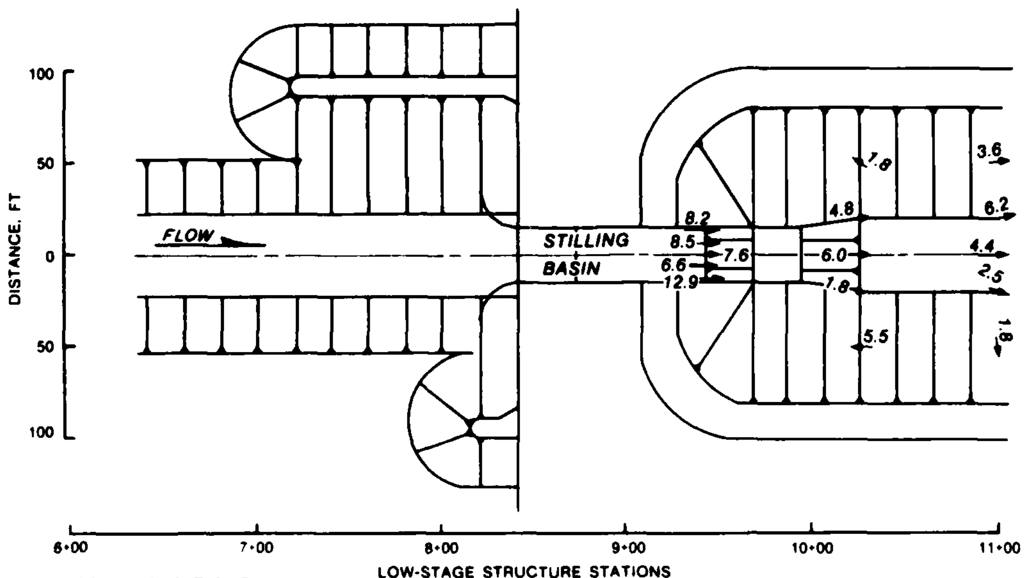
MODIFICATIONS TO EXIT CHANNEL

PLATE 19



TEST CONDITIONS
DISCHARGE 14,800 CFS
POOL EL 240.0
TAILWATER EL 234.3

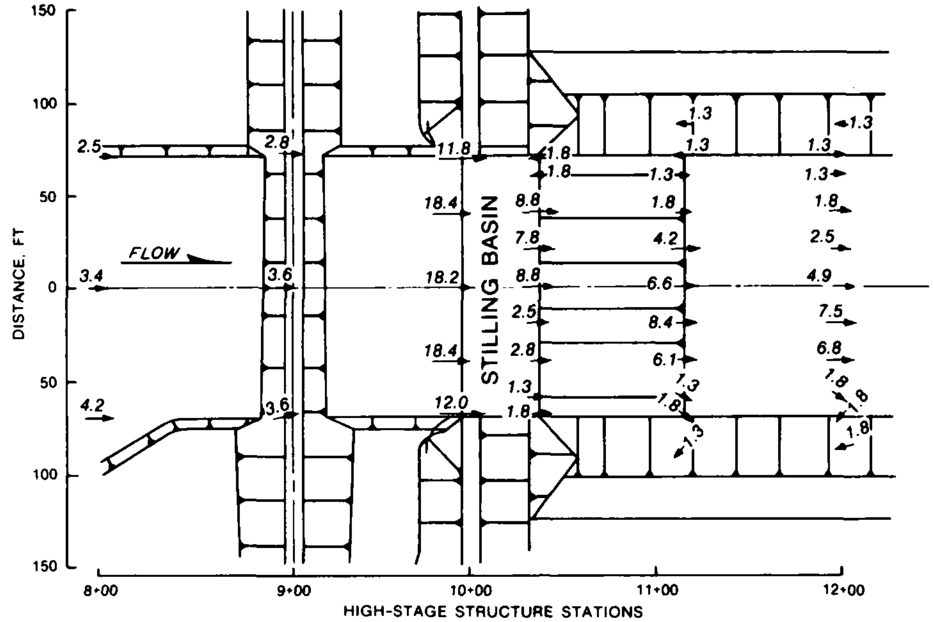
NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND TAKEN 1 FT OFF BOTTOM AT THE END SILL AND STATIONS 10+24.33 AND 11+00, AND 2 FT OFF THE BOTTOM AT STATIONS 8+00, 8+40, AND 9+00.



TEST CONDITIONS
DISCHARGE 14,800 CFS
POOL EL 240.0
TAILWATER EL 233.0

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND TAKEN 1 FT OFF BOTTOM

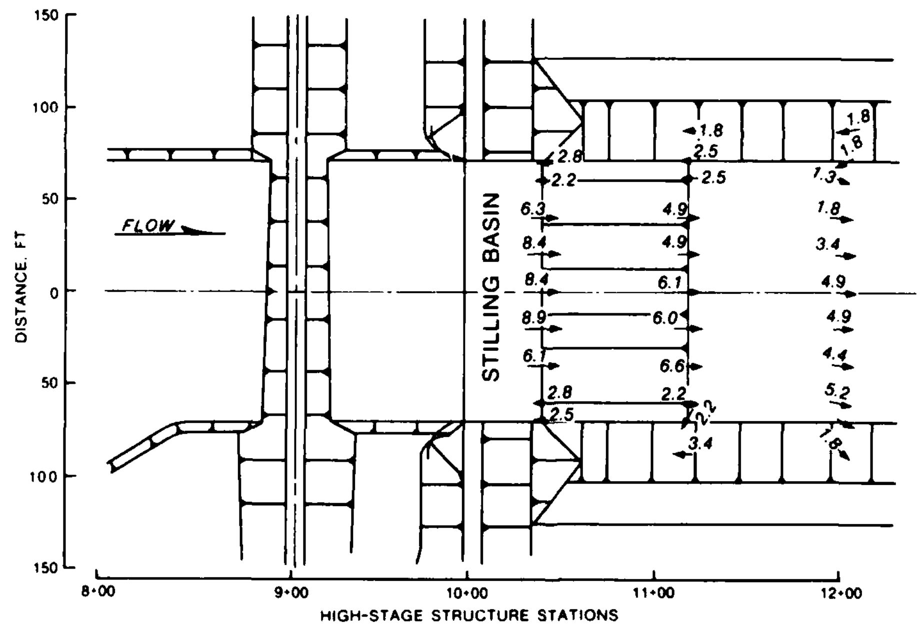
LOW-STAGE STRUCTURE
VELOCITIES
TYPE 4 DESIGN CREST
TYPE 7 DESIGN APPROACH WING WALLS
39-FT BOTTOM WIDTH IN EXIT CHANNEL



TEST CONDITIONS

DISCHARGE 14,800 CFS
POOL EL 234.3
TAILWATER EL 234.3

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND TAKEN 1 FT OFF BOTTOM AT END SILL, STA 11+15 AND STA 12+00 AND 2 FT OFF BOTTOM AT CREST STA 9+00 AND STA 8+00.



TEST CONDITIONS

DISCHARGE 14,800 CFS
POOL EL 240.0
TAILWATER EL 233.0

NOTE VELOCITIES ARE IN PROTOTYPE FEET PER SECOND TAKEN 1 FT OFF BOTTOM

HIGH-STAGE STRUCTURE
VELOCITIES
TYPE 6 DESIGN
APPROACH WING WALLS
TYPE 2 DESIGN RIPRAP PLAN
141-FT BOTTOM WIDTH IN EXIT CHANNEL

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.